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Report 1808

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DAVID TAYLOR MODEL BASIN
WASHINGTON D.C.

DEPARTMENT OF THE NAVY

HYDROMECHANICS

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AERODYNAMICS

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STRUCTURAL MECHANICS

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APPLIED MATHEMATICS

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ACOUSTICS AND VIBRATION

AUTEC ACOUSTIC TRACKING SYSTEM

by

Charles G. McGuigan
and
C. Leland Bolen

UNDERWATER ACOUSTICS OFFICE
RESEARCH AND DEVELOPMENT REPORT

January 1964

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ABSTRACT

This report describes the Acoustic Tracking System to be used during operation of the Atlantic Undersea Test and Evaluation Center (AUTEC) Acoustic Range. The system is designed primarily to track a submarine relative either to a floating vertical array (MONOB-I) or to a bottom-mounted fixed array of noise-measuring hydrophones (AUTEC).

I. INTRODUCTION

The Atlantic Undersea Test and Evaluation Center (AUTEC) Acoustic Tracking System (ATS) was designed primarily to track a submarine relative either to a standard portable array (Fig 1) or to a bottom-mounted fixed array (Fig 2) of noise-measuring hydrophones. It is the Navy's intention to use the tracking data to assist in obtaining noise measurements of submarines during test conditions and to aid the navigator when operating in the vicinity of the array.

The AUTEC Acoustic Tracking System (ATS) was conceived by the David Taylor Model Basin and the tasks of design, manufacture, and test were awarded to International Business Machines under the cognizance of the Bureau of Ships and the Taylor Model Basin.

General requirements for the system were as follows:

1. The active mode of the system must be capable of automatic or manual shutdown during the acoustic measurement period. When in the quiet zone, the laboratory ship equipment can continue generating range and bearing outputs for use in the magnetic tape instrumentation.

2. The system must be capable of operation with a mobile hydrophone array or with a similar array mounted to the bottom.

3. The entire system must be capable of operation in a State 2 sea.

4. All underwater components must be capable of operation under the following conditions:

   a. Pressures up to 1500 psi.

   b. Prolonged submerged periods without the necessity for repairs.

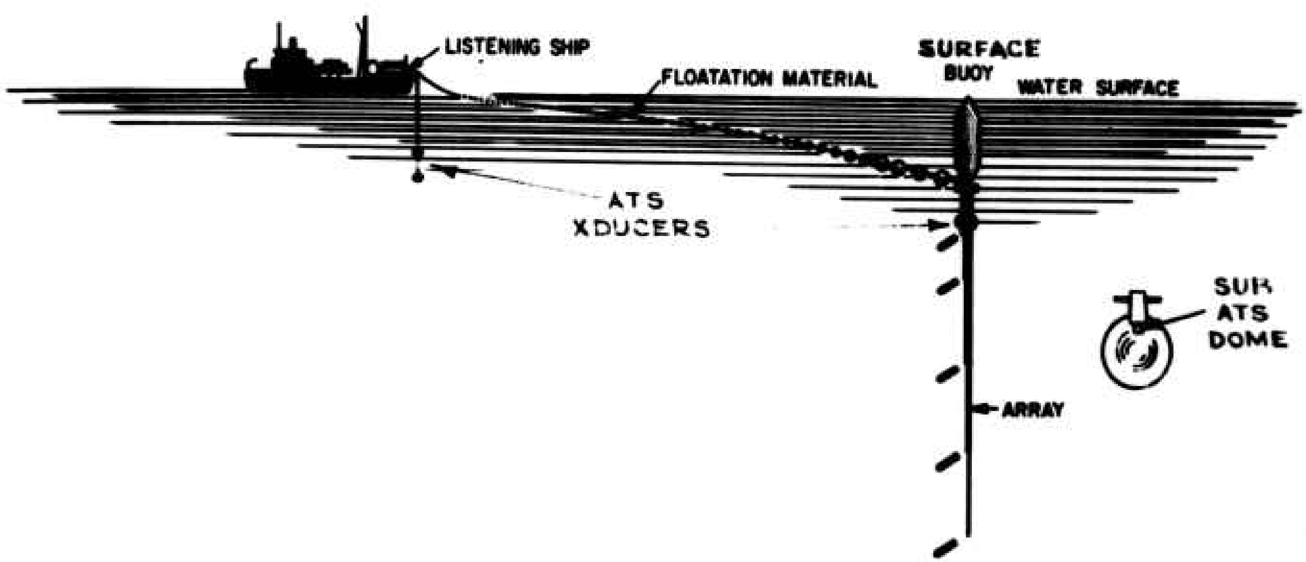

Figure 1 - Standard Portable Array

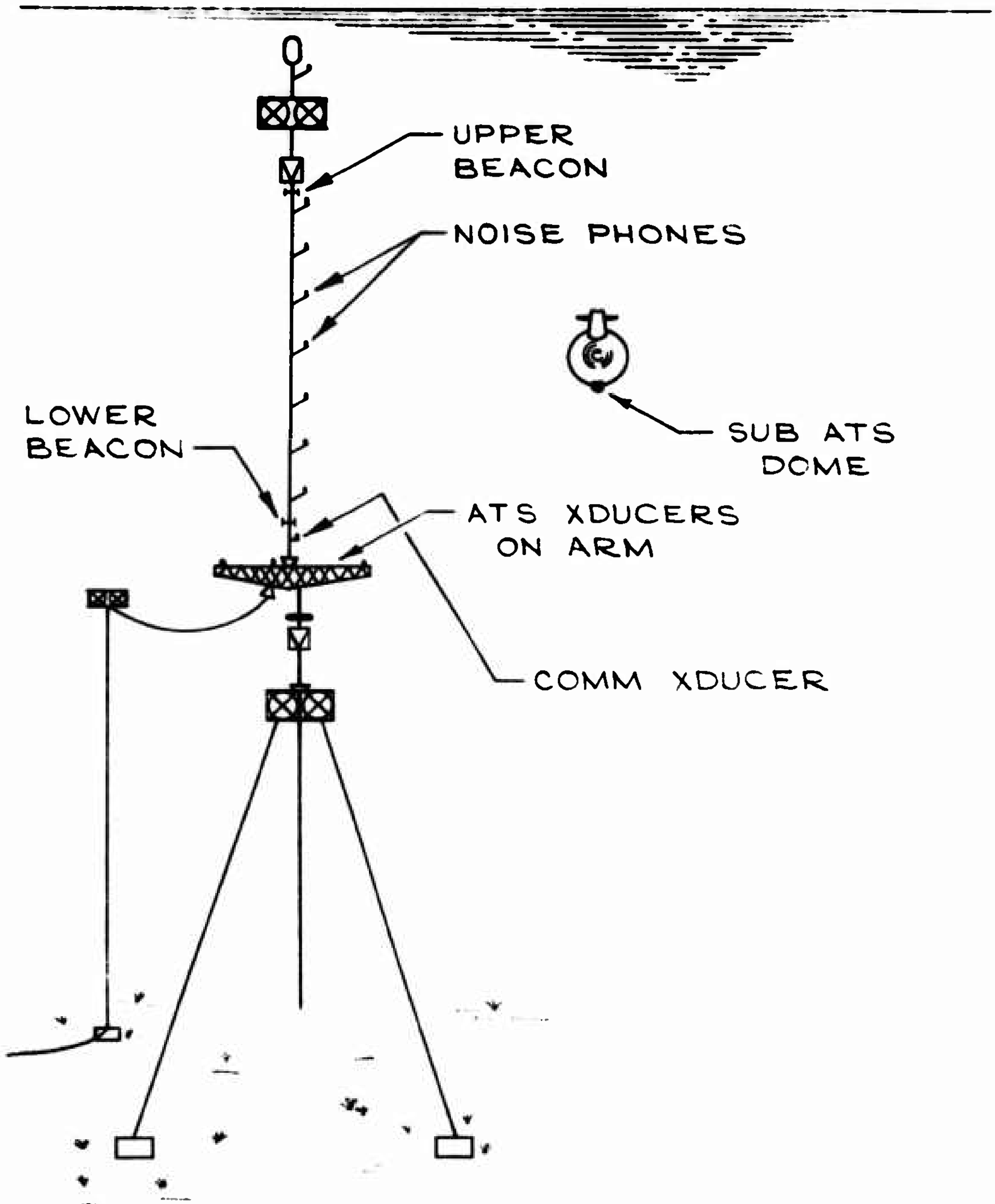

Figure 2 - Autec Bottom-Mounted Array

1. Submarine mounted elements up to 6 mo.

2. Array mounted elements up to 5 yr.

5. Range Accuracy - The slant range errors must be less than 3 percent of the range for horizontal ranges greater than 100 yd.

6. Bearing Accuracy - The errors in submarine bearing must be less than ± 2 deg for the area external to that bounded by horizontal ranges less than 500 yd and bearing angles less than ± 15 deg from the Y-axis about the coordinate origin.

II. DESCRIPTION OF SYSTEM

The ATS performs measurements of the time required for an acoustic pulse emitted by an underwater projector on a submarine to reach two hydrophones which are separated by a known or measured distance. It is assumed that both hydrophones are in a plane parallel to the surface or that the tilt of the plane with respect to the surface is known. (See the Appendix for AUTEC MATHEMATICS). It is also assumed that the depths of the tracking hydrophones and the submarine are known. Slant ranges (R_S), horizontal ranges, (R_H), and bearings (θ) of the submarine relative to the tracking hydrophones can be computed from a knowledge of the acoustic travel times, acoustic velocity of propagation, separation of the hydrophones, and depths of hydrophones and submarines. From these parameters, the X and Y coordinates of the submarines can be obtained.

Precision real time clocks on both the submarine and the laboratory ship (which can be synchronized) permit the total travel time to each hydrophone to be measured. The measurements and computations are performed automatically by a real time control processor according to a

stored program. The stored program (on paper tape) is loaded into the processor utilizing a paper tape reader and requires approximately 6 min for loading. An insert mode is provided in which parameters, which can change from run to run such as depth of submarine, depths of tracking hydrophones A and B, ping period (3.3, 6.67, 13.33, and 26.6 sec), and the limits of the quiet zone are hand loaded by means of rotary switches. A calibration mode is provided in which the ATS system on both MONOB and the submarine are connected to FM radio transceivers to permit the automatic phase calibration of the real time clocks. Such a calibration procedure is required daily and is automatic upon patching to the transceivers and setting appropriate mode switches; the submarine must of course come to the surface for clock calibration. An operating mode is provided which permits automatic tracking of the submarine.

Submarine track relative to the tracking baseline* is provided as a visual display on an X-Y recorder. Horizontal range of the submarine and bearing of the submarine relative to the tracking baseline are typed out upon request. In addition, analog signal outputs proportional to horizontal range, bearing, and slant ranges to five array hydrophones are provided for storage on magnetic tape for use in interpretation of noise data. Three navigation parameters (horizontal range to array, true bearing angle to array, and track error) are communicated to the submarine via digital acoustical pulses using a UQC projector located on the AUTEC array.

*MONOB array has a tracking baseline of 300 ft positioned approximately 50 ft below the ocean surface. The AUTEC array contains a fixed tracking baseline of approximately 46 ft which is located 1500 ft below the ocean surface.

Additional control numbers are communicated which determine a quiet zone when acoustic noise measurements are to be made; these controls silence the submarine tracking projector upon entrance into the quiet zone and provide for the emission of a single pulse at the predicted closest point of approach. As previously noted, the extent and location of the quiet zone can be set by the operator prior to any run. The data communicated are also displayed as an output on the typewriter on request.

Equipment on the laboratory ship* is capable of the following:

1. Accepting signals from two tracking hydrophones; the signal is generated by the projector on the submarine.

2. Accepting signals from five noise-sensing hydrophones; the noise is generated by the projector on the submarine being tracked.

3. Providing a calibration technique for synchronizing the equipment aboard the laboratory ship and the submarine.

4. Processing the signals received on the two tracking hydrophones during the period when the submarine is pinging** so that the submarine can be tracked relative to the hydrophone array.

5. Providing the following tracking information to the below listed peripheral equipment:

a. X-Y plotter - position of submarine in X and Y axes for every ping position of the submarine (once per ping period). The Y axis

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*It is anticipated that equipment similar to that now installed on the laboratory ship (MONOB I) will be installed in a shore laboratory near the site of the bottom-mounted array. Connections from the array hydrophones to the shore laboratory will be by multi-conductor cable. It is expected that the shore laboratory will be available in (calendar year) 1965.

**It should be noted that the term pinging as used herein refers to short pulses emitted by the tracking equipment installed on the SS-<u>not</u> sonar pings.

coincides with the projection of the axis of the tracking arm on a horizontal plane; the X axis is also in the horizontal plane and is perpendicular to the Y axis.

b. Magnetic tape unit - position of the submarine in horizontal range (R_H), slant range (R_S), and submarine bearing (Θ) relative to the array approximately four times per period during the course of the operational run; analog signals are provided corresponding to the extrapolated position of the submarine relative to five noise-measuring hydrophones during the quiet zone.* This includes (R_H), (R_S) and Θ; Θ is the angle whose tangent is $\frac{x}{y}$.

6. Extrapolated data are provided to the equipment listed in 5.a and 5.b above when a ping is "missed" during operation outside of the quiet zone.**

7. Submarine navigation information is provided to an output device for transmission to the submarine over the UQC acoustic link.

8. The following navigation information is provided to the submarine during every ping period:***

a. R_H - horizontal range of the submarine from the array.

b. ϕ - array bearing true to submarine velocity vector.

c. $\mathcal{E}$ - lateral deviation of the submarine from the desired track.

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*The quiet zone is defined as the portion of the target ship's track during which the tracking equipment on the target ship ceases to ping and return communications to the target ship are shut off in order to avoid interference with the noise measurements.

**If for any reason a ping is not received or fails to activate the processor, the processor automatically enters the extrapolate mode of operation and remains in this mode until an acceptable ping is subsequently received.

***A ping period is the time between any two successive pings.

d. N_1 - A control quantity to automatically silence the submarine "pinger" when the submarine reaches the quiet zone.

e. N_2 - A control quantity to automatically pulse the pinger at the point when the submarine is closest to the hydrophone array and also to automatically energize the pinger upon the exit of the submarine from the quiet zone.

9. Upon operator request, an automatic written record of constants used throughout the run is provided and also a record of the range of the submarine to the five noise-sensing hydrophones at the point of closest approach and at the points when the submarine enters and leaves the quiet zone.

The submarine equipment is capable of the following:

1. Providing a calibration method for synchronizing the equipment aboard the laboratory ship and the submarine.

2. Providing a method of pulsing the tracking projector ("pinger") at the prescribed time intervals.

3. Providing a method of accepting the navigation information from the laboratory ship.

4. Providing the necessary equipment for displaying the following quantities to the operator: range (R_H), array bearing (ϕ), and lateral deviation from the prescribed course ($\mathcal{E}$).

5. Providing the necessary controls to accept the quantities N_1 and N_2 being sent from the laboratory ship to control the "pinger" during all portions of the trial operation.

Block diagrams of the laboratory ship equipment and submarine equipment are listed in Fig 3 and Fig 4. A 3 axis geometrical presentation of the coordinate system used in tracking is indicated in Appendix A.

III. EQUIPMENT SYSTEMS

The equipment supplied as part of the acoustic tracking system can be logically separated into laboratory ship equipment and submarine equipment.

A. LABORATORY SHIP EQUIPMENT

The laboratory ship equipment is a permanent installation aboard MONOB I (Fig 5). It consists of a processor cabinet measuring 24 in. wide X 67 in. high X 24 in. deep. The I/O cabinet and system operating console measures 18 in. wide X 50 in. high X 24 in. deep. In an adjacent relay rack are mounted the paper tape reader, typewriter, 5-mc oscillator, and power supplies. The plotter is installed on the laboratory trial director's console. The three units of equipment are installed adjacent to one another at one end of Laboratory 2 on MONOB I. The equipment is connected to a single source of 110 v ac and requires 30 amp.

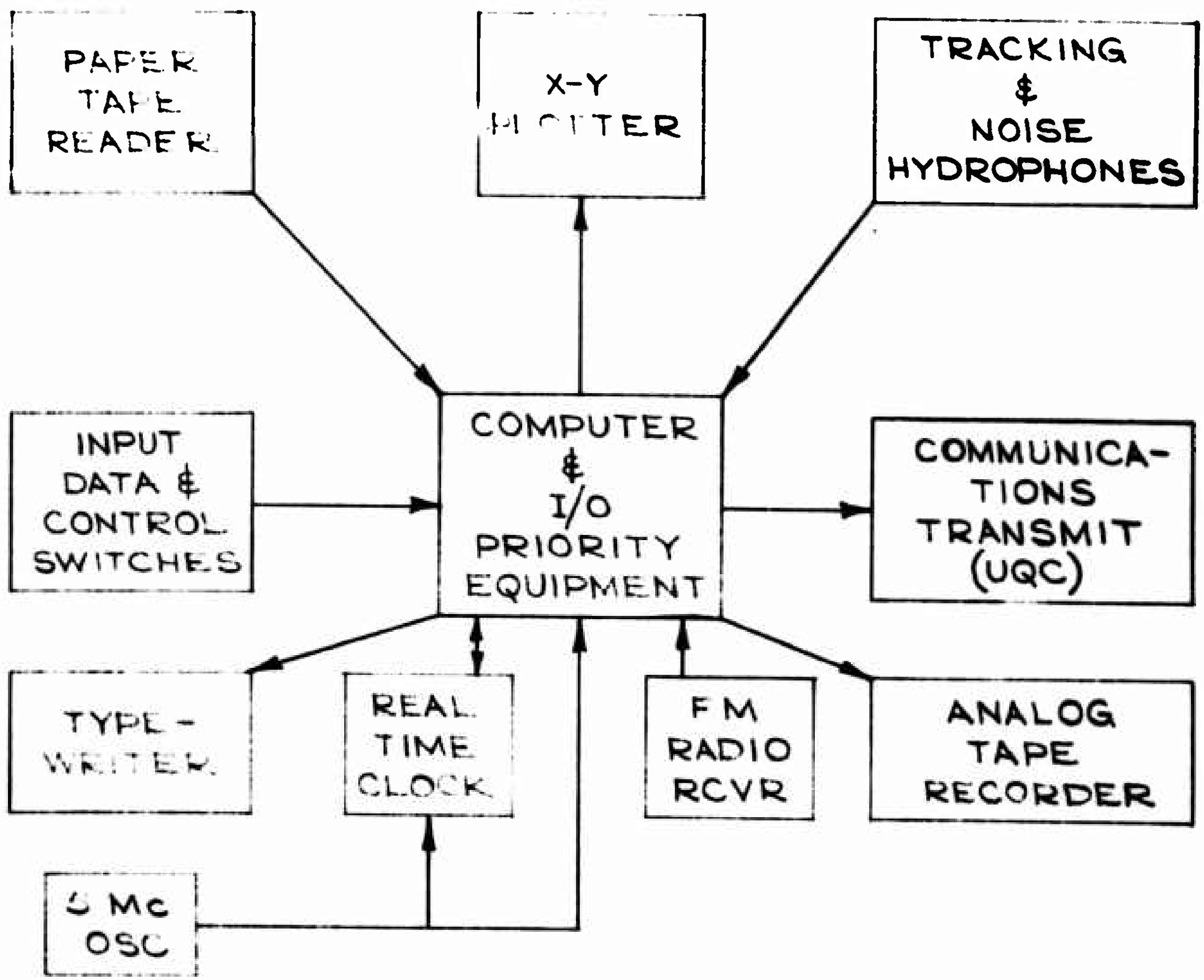


Figure 3 - MONOB I ATS Equipment

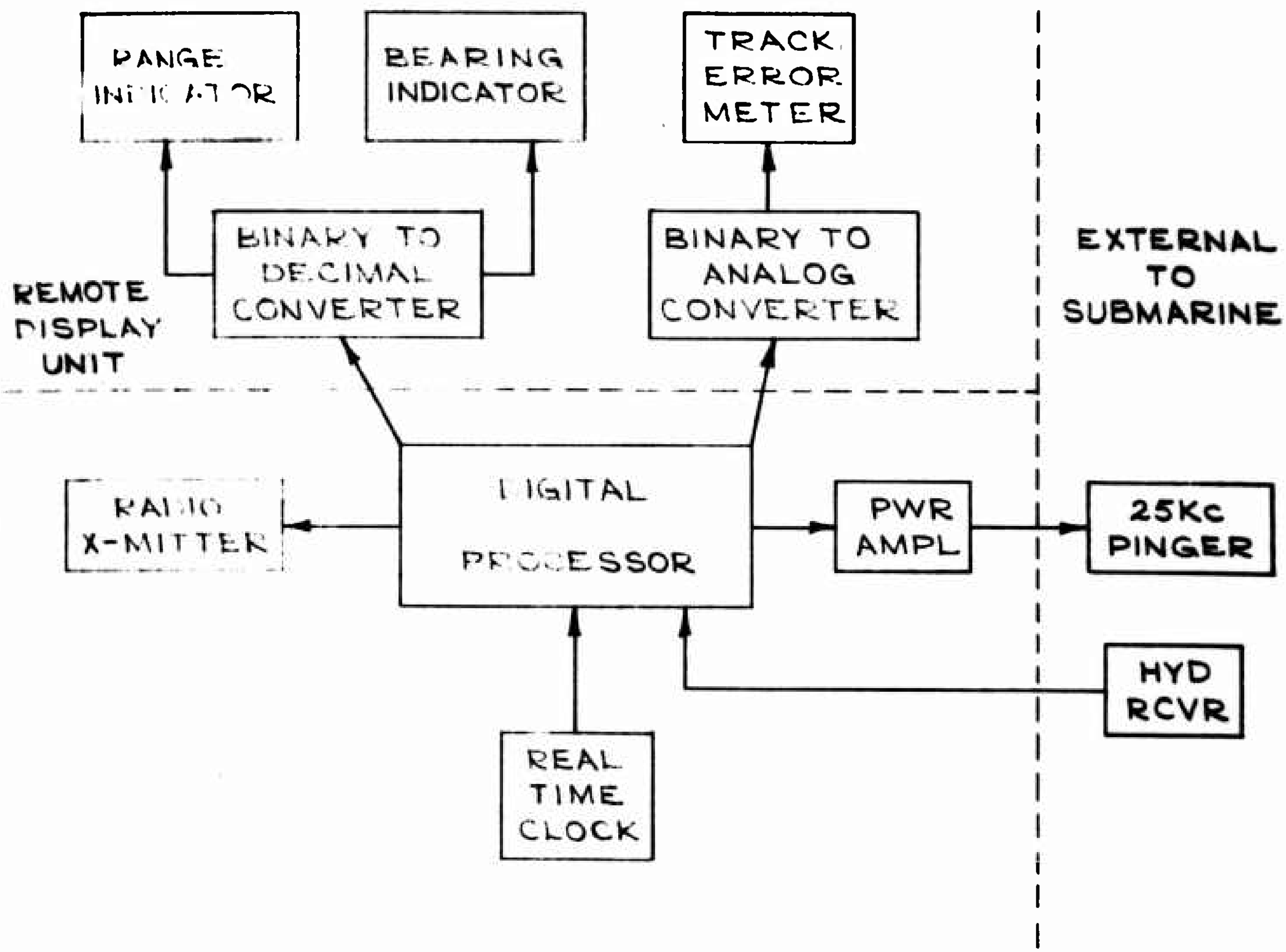
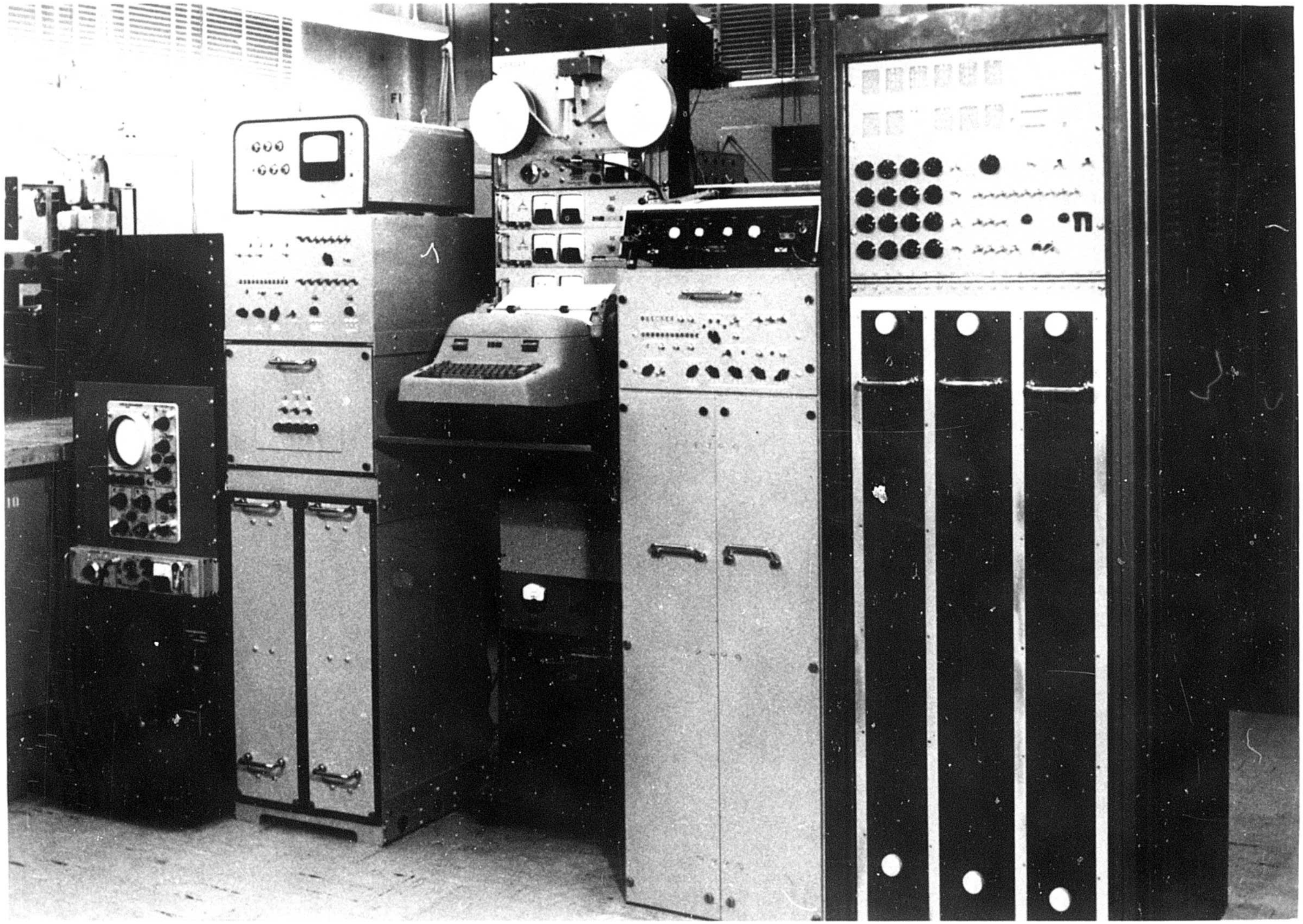


Figure 4 - Submarine ATS Equipment



Submarine Consoles   Laboratory Vessel Consoles

Figure 5 - ATS Computer and Peripheral Equipment

For utilization of the system with the AUTEC array, input connections are required to two of the tracking hydrophones and any five noise-measuring hydrophones. System output connections must be made to the MONOB UQC and an Ampex recorder through the subcarrier channels. Another system input/output connection required is to an FM transceiver for the purpose of phase calibration.

For utilization of the system with the floating array, two tracking hydrophones and an acoustic projector are supplied as part of the ATS and serve as inputs in place of the AUTEC tracking hydrophones. Output connections remain identical to those for AUTEC.

B. SUBMARINE (TEST VEHICLE)

ATS equipment (Fig 5) required to be installed on the submarine consists of three pieces of electronic gear and two acoustic transducers mounted external to the submarine. The electronic gear consists of a processor housed in a package measuring 18 in. wide X 56 in. high X 25 in. deep. Peripheral gear (consisting of a power amplifier, power supply, oscilloscope, and a precision oscillator) is mounted in a standard size relay rack measuring 53 in. high. The processor equipment can be broken down into three parts to allow easier handling, and all items can pass through a standard submarine hatch. The equipment operates on 110 v ac and requires a standard a-c outlet capable of providing 10 amp. A remote display unit (Fig 6) measuring 18 in. wide X 8 in. high

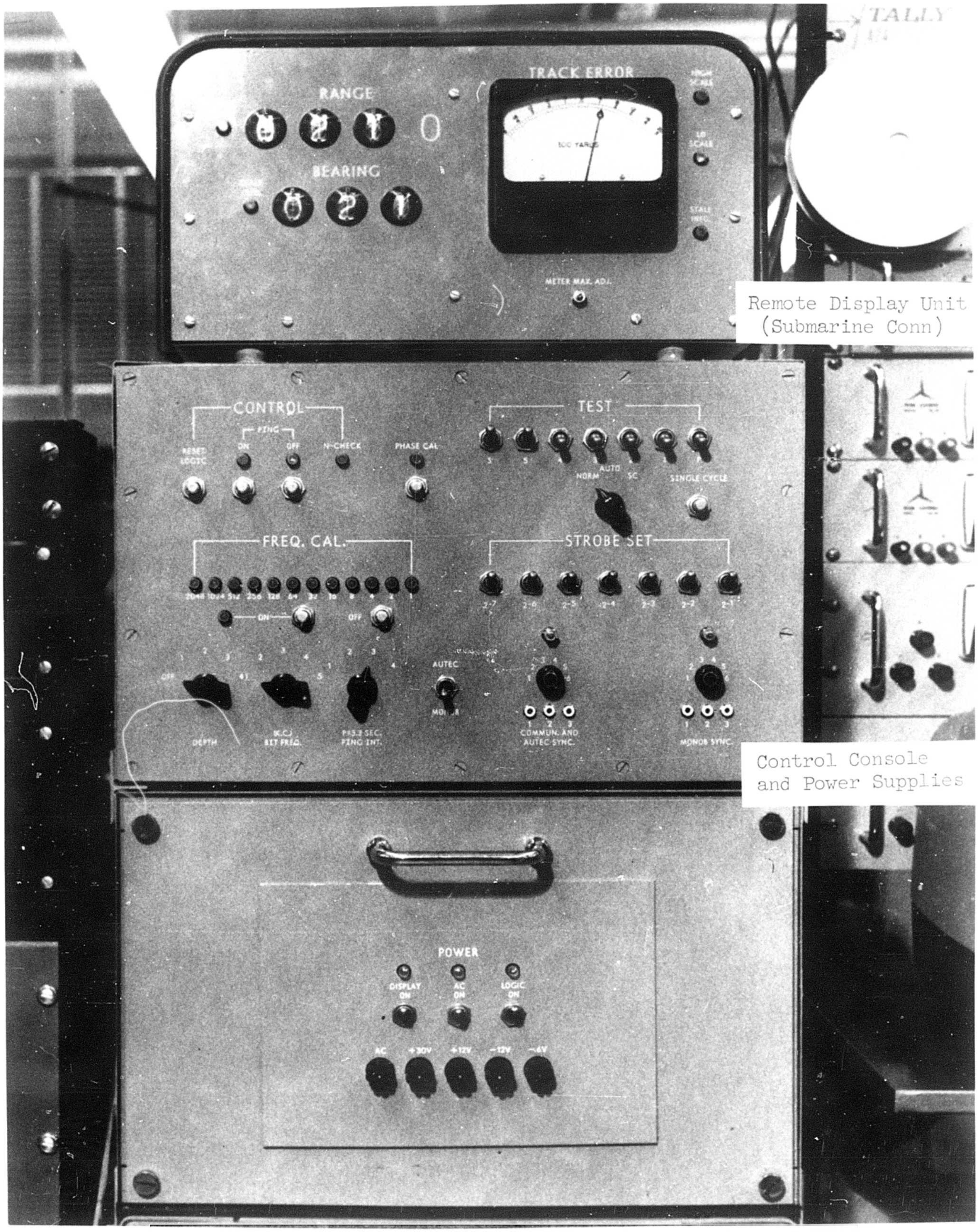


Figure 6 - Part of Submarine ATS Equipment

X 15 in. deep can be placed upon the top of the processor equipment or mounted remote to the processor gear. A cable 9/16 in. in diameter, 130 ft in length, and containing 54 conductors is provided for operating the display remote to the remaining submarine equipment. It is suggested that the remote unit be placed in the submarine conning tower since it presents visual data to assist in the navigation of the submarine relative to the AUTEC array. All other electronic equipment can probably be installed in the forward battery compartment, or as designated by the test vehicle.

Another requirement is the mounting of a small streamlined fiberglass dome (Fig 7, Fig 8, Fig 9, Fig 10) enclosing two transducers which are part of the ATS. The dome is normally supplied by the Model Basin and should be placed under the existing sonar dome in the case of conventional fleet submarines. In the FBM type submarine, a desirable location is the underside of Ballast Tank 1A. It is necessary to mount the dome with the transducers to the submarine hull, where two hull penetrations are required to accomodate the transducer cables. It is preferable to drydock the submarine to permit dome-transducer attachments although the installation can be performed by divers. The mounting position differs depending on whether the AUTEC array or floating array is to be utilized. For tests with the AUTEC array, it is necessary to mount the transducers on the bottom side of the submarine hull; for tests with the MONOB floating array it is necessary to mount the transducer topside. A decision as to the exact location of dome mounting will be made at time of drydocking depending on what array will be utilized.

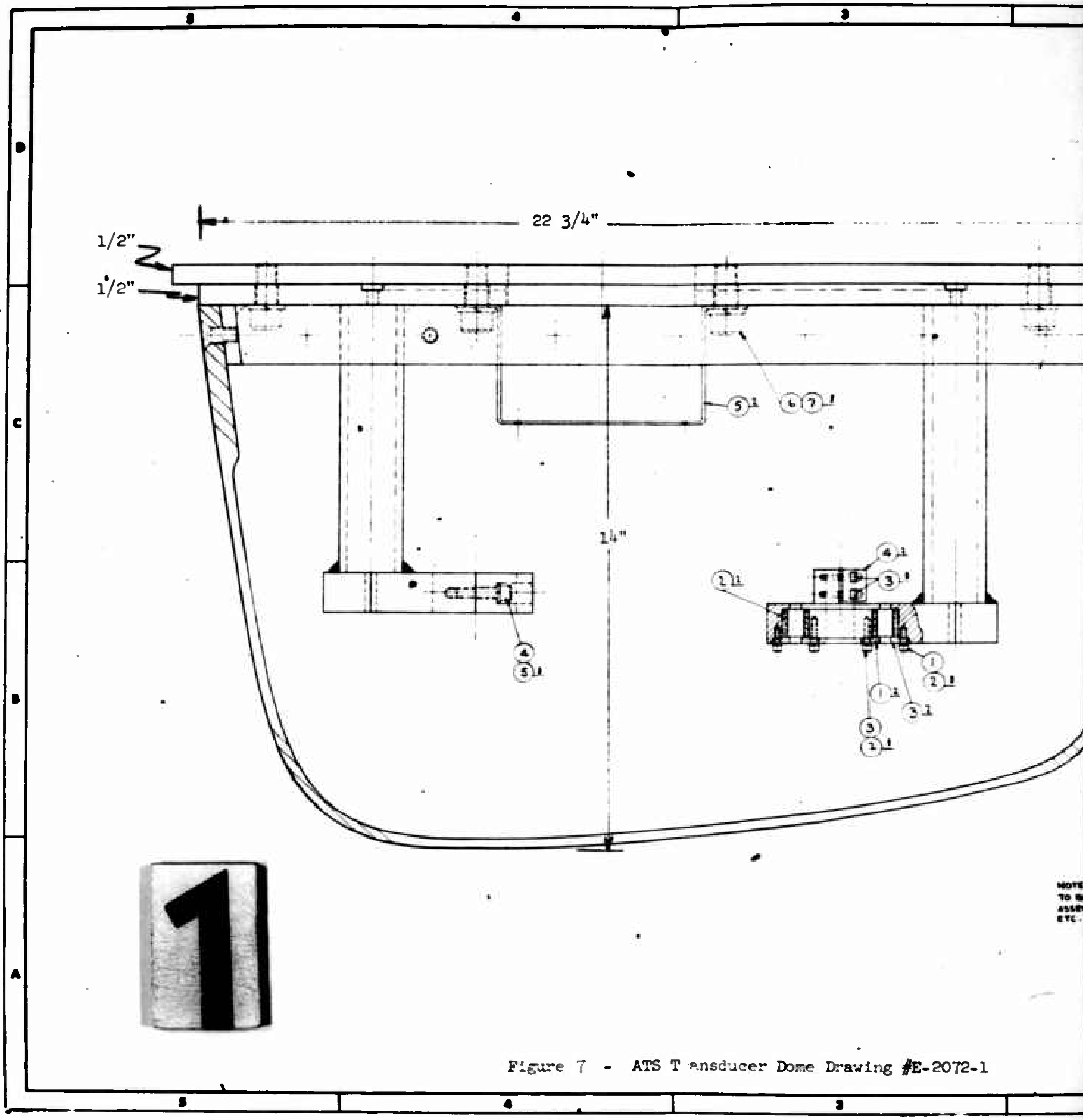


Figure 7 - ATS Transducer Dome Drawing #E-2072-1

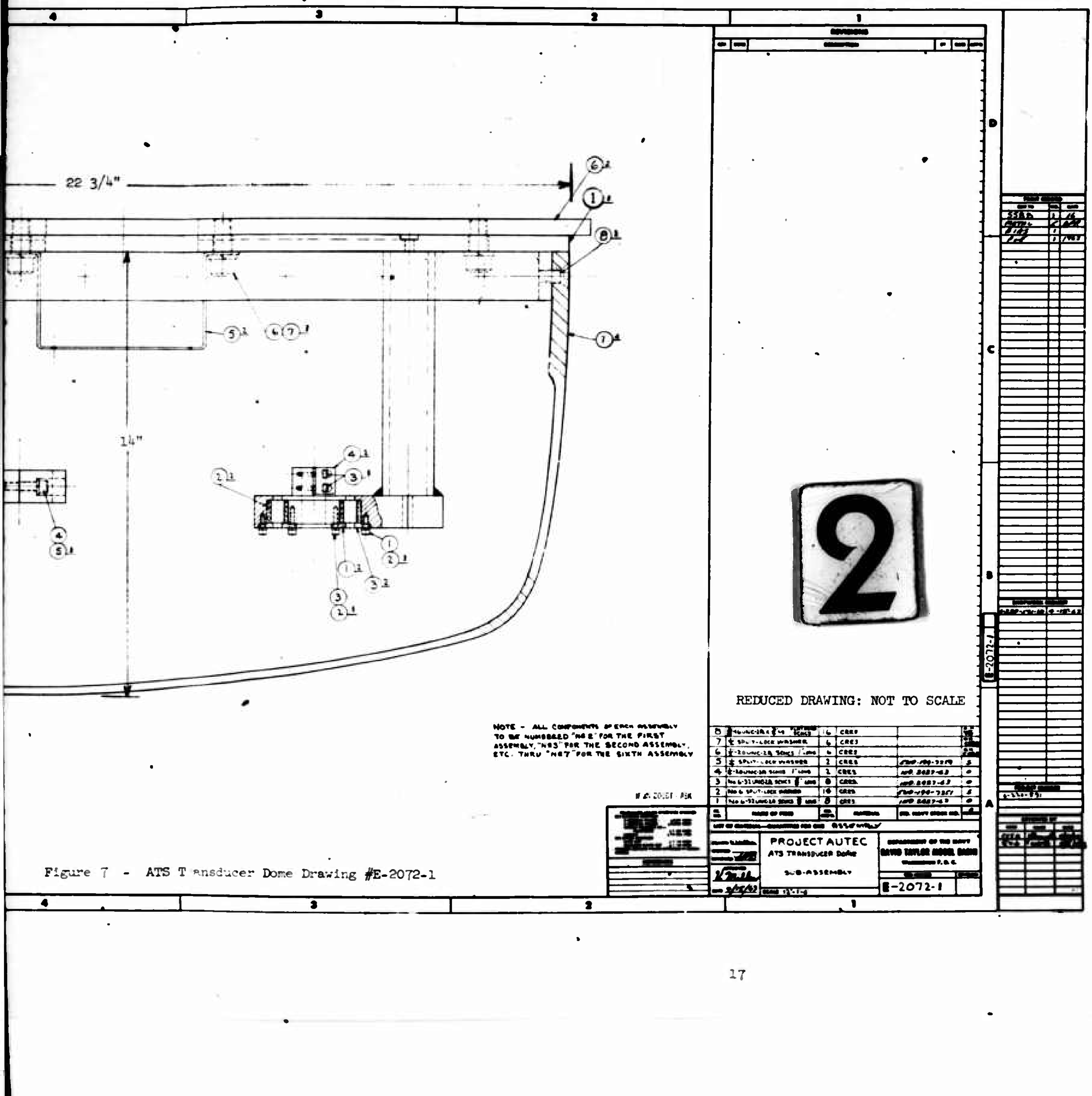
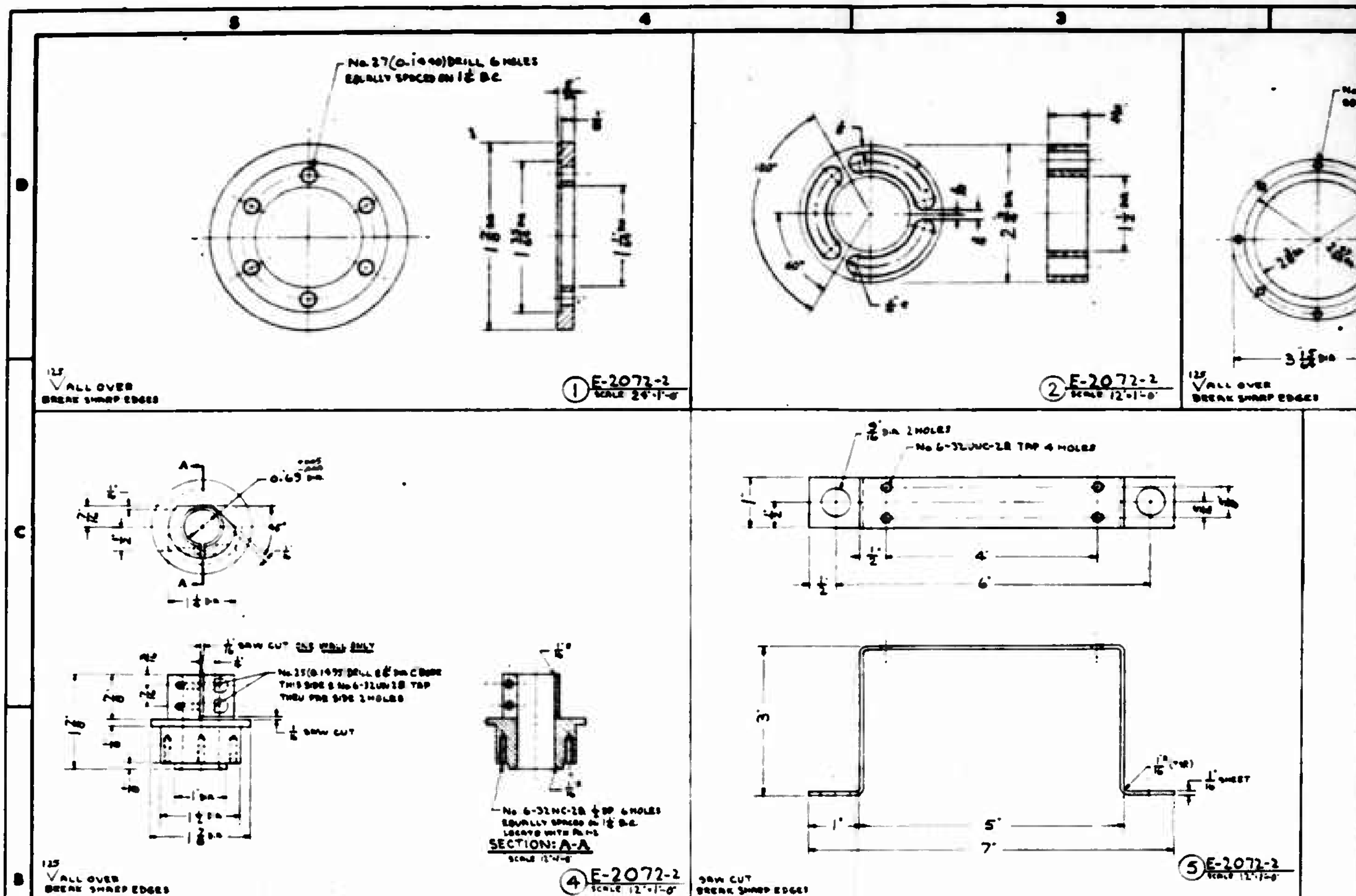


Figure 7 - ATS Transducer Dome Drawing #E-2072-1


No. 27 (0.1440) DRILL, 6 HOLES EQUALLY SPACED ON 1½ B.C.
ALL OVER
BREAK SHARP EDGES
1 E-2072-2
2 E-2072-2
No. 6-32UNC-2B TAP 4 HOLES
SECTION: A-A
4 E-2072-2
SAW CUT
BREAK SHARP EDGES
5 E-2072-2

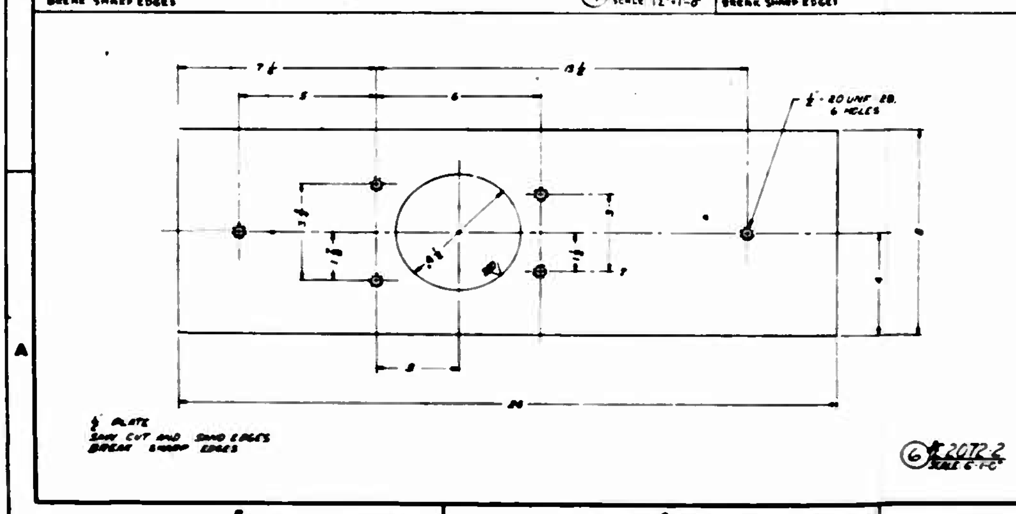
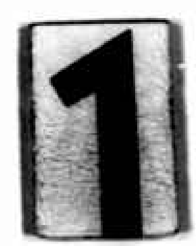

¼-20 UNF 2B. 6 HOLES
SAW CUT AND SAND EDGES
BREAK SHARP EDGES
6 E-2072-2

Figure 8 -



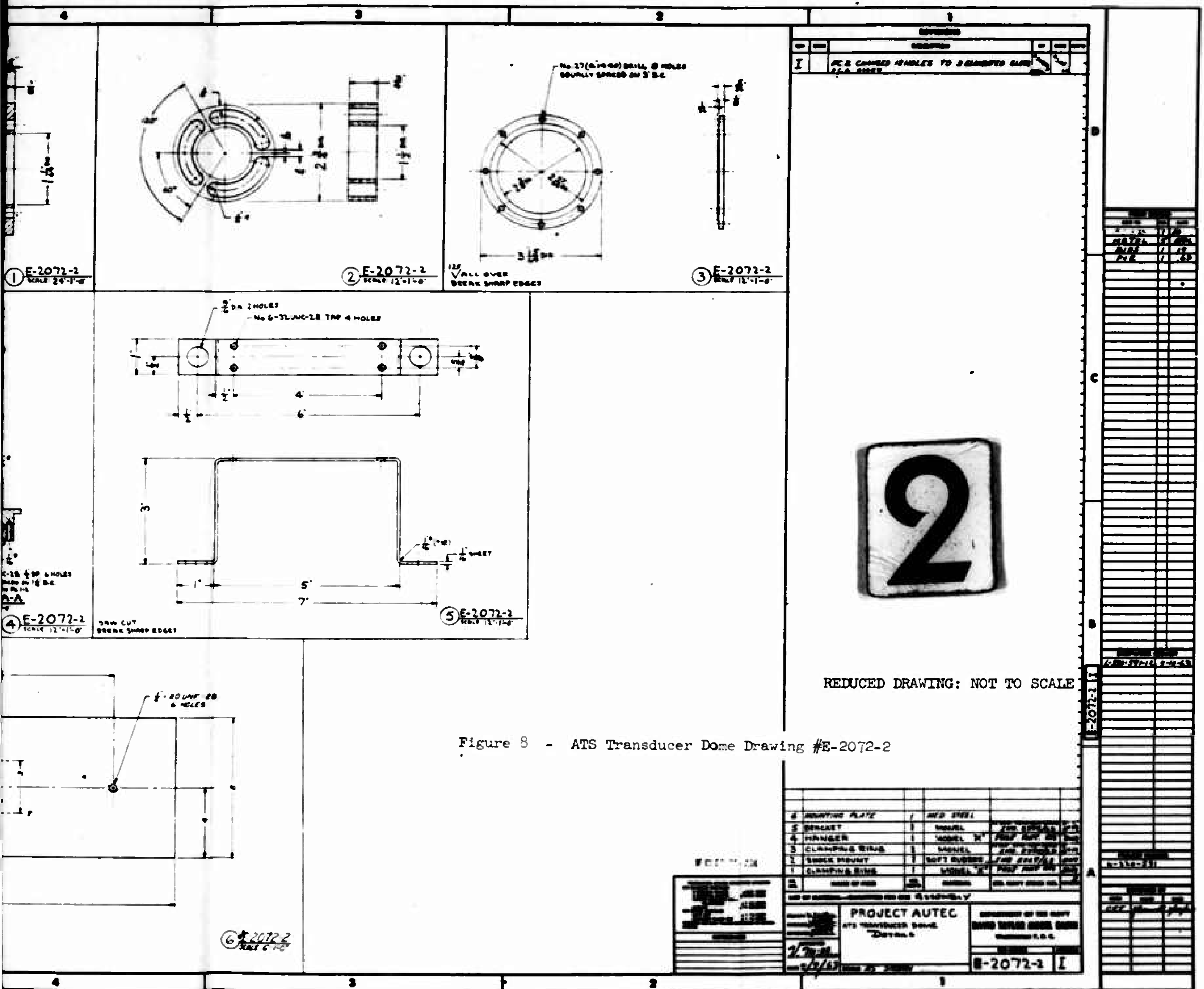


Figure 8 - ATS Transducer Dome Drawing #E-2072-2

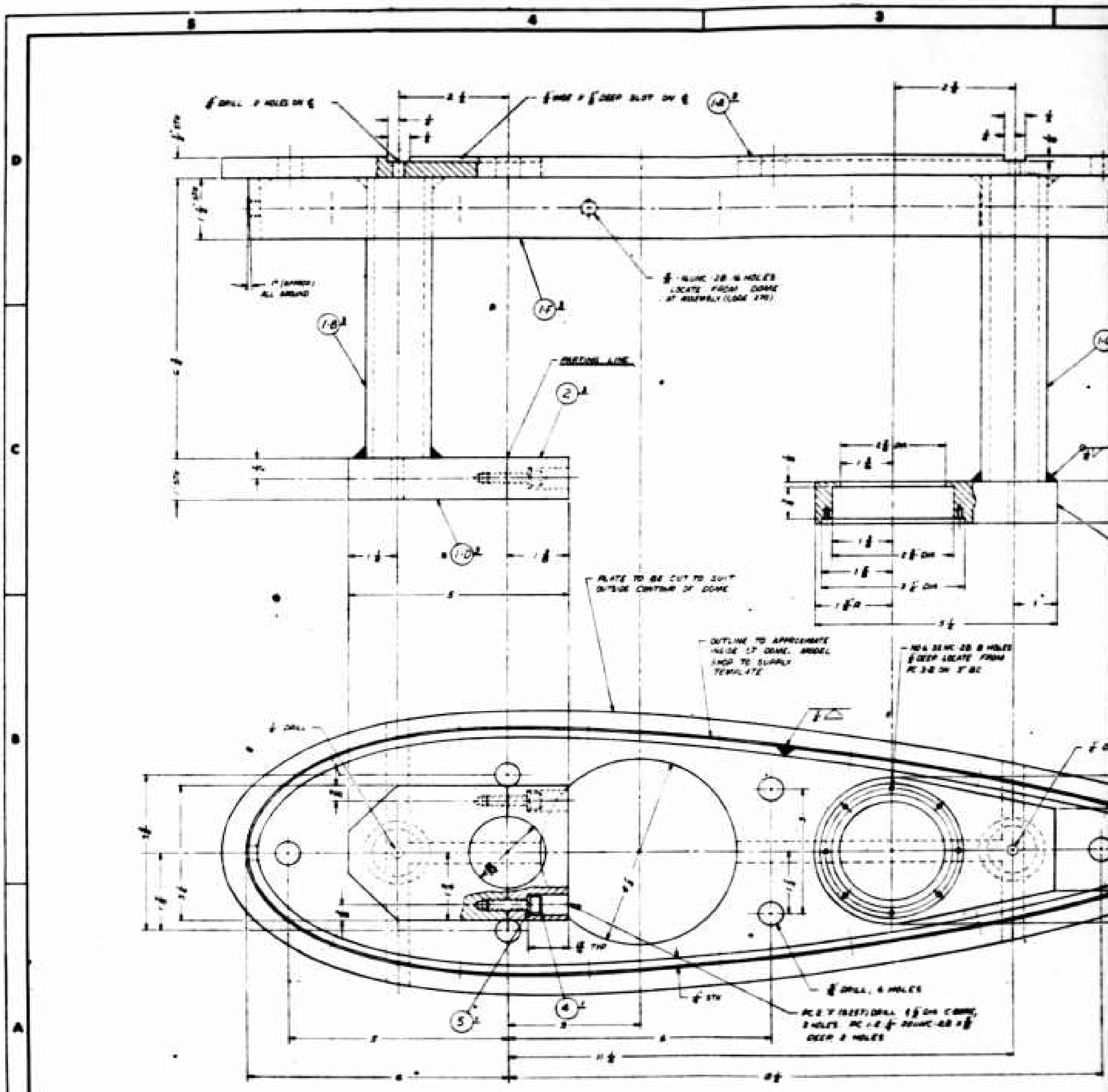
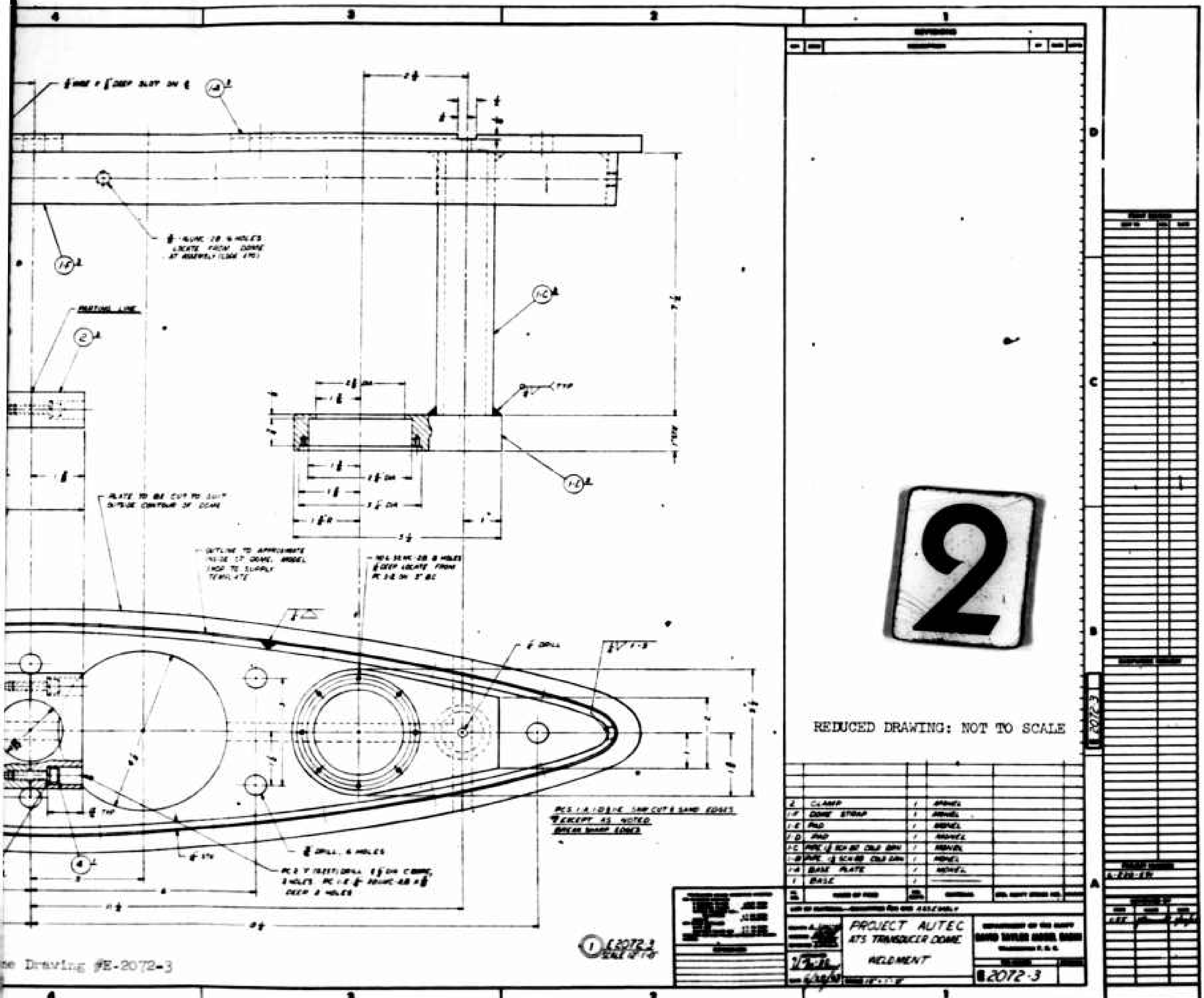


Figure 9 - ATS Transducer Dome Drawing #E-2072-3



PARTING LINE
PLATE TO BE CUT TO SUIT OUTSIDE CONTOUR OF DOME
REDUCED DRAWING: NOT TO SCALE
CLAMP
DOME STRAP
PAD
PAD
BASE PLATE
BASE
MONEL
PROJECT AUTEC
ATS TRANSDUCER DOME
WELDMENT
E2072-3
he Drawing #E-2072-3

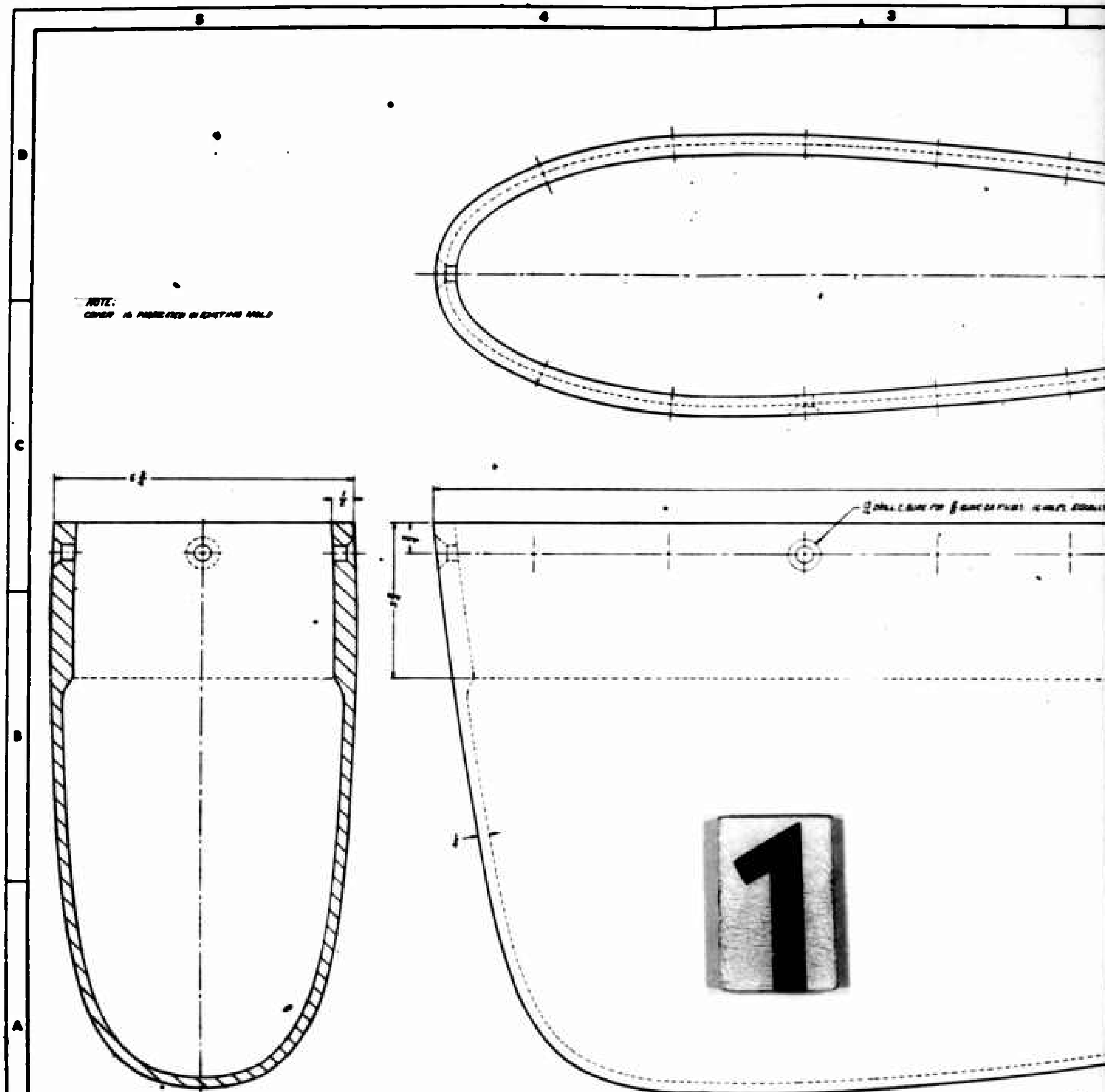
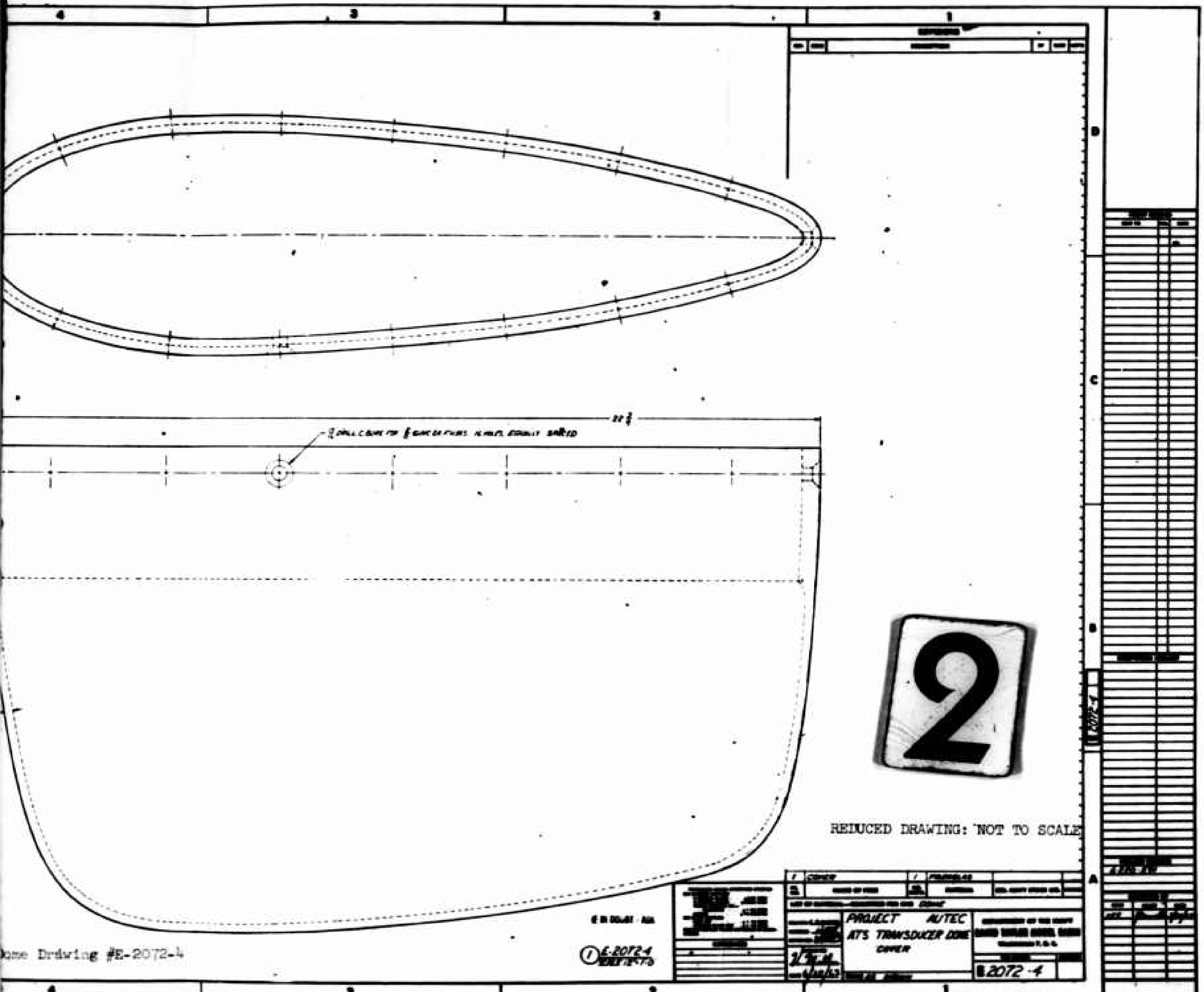


Figure 10 - ATS Transducer Dome Drawing #E-2072-4



Dome Drawing #E-2072-4

Installation of the remote display cable extending from the conning tower to the location of the other test gear is normally required while the test vehicle is in port. Another cable (1/4 in. in diameter, single conductor shielded cable) must be installed between the FM transceivers (installed by the Model Basin for communication purposes) and the submarine processor. This cable is required to enable the real time clock in the submarine processor to be phase calibrated via FM radio link with an equivalent clock on MONOB.

IV. OPERATIONAL USE OF THE ACOUSTIC TRACKING SYSTEM

In order to familiarize personnel with the operational use of the ATS, which is part of the AUTEC System for measuring the radiated noise of submarines, the following tentative operational procedures have been formulated. It is anticipated that many changes will occur before sufficient experience has been accumulated through actual trials to evolve an optimum procedure.

The following sequence of actions and procedures are considered necessary for any submarine noise trial utilizing the ATS as part of noise measurement trials.

A. ATS EQUIPMENT INSTALLATION REQUIRED PRIOR TO CONDUCT OF FIELD TRIAL

All equipment on MONOB described in Section III. A. is considered as part of the permanent installation aboard MONOB. After scheduling a specific submarine for an AUTEC sound trial and prior to the actual test, a drydocking of the submarine is required for installation of the ATS acoustic transducers enclosed in a small streamlined dome

external to the submarine hull including the necessary cabling. In certain cases mounting of the dome is required topside of the submarine, wherein drydocking is not necessary. All equipment described in Section III. B. will be installed whenever practicable prior to arrival of the test vehicle at the test site.

1. Installation of two cables (to be supplied) which are part of the projector and hydrophone must pass through the pressure hull to the ATS electronic equipment inside the submarine. If possible, all ATS equipment must be installed on the submarines prior to the test, while the submarine is in drydock, with the exception of the precision oscillator which will be installed at the test site. Should a great lapse of time between drydocking and actual acoustic trials occur, then it is suggested that only the cables and dome be installed at the drydocking. The electronic computer and associated equipments could then be installed alongside a pier prior to trial time. After the equipment is installed, it should be checked out insofar as practicable in order to insure proper operation.

B. CALIBRATION AND CHECKOUT PROCEDURES REQUIRED AT TEST SITE IMMEDIATELY PRIOR TO START OF TRIAL

To insure proper system operation, the following procedures are recommended.

1. ATS (MONOB) Checkout

The checkout of the ATS equipment aboard MONOB can be initiated at any time independent of submarine operation. After power is turned on and the equipment allowed to warm up, a temperature light on the

computer indicates when the core memory operating temperature has been reached and stabilized. The coded program on paper tape must be loaded and verified. The desired parameters for each run are entered in decimal form into the computer by means of five (5) BCD rotary switches which appear on the system console. The switch at the extreme left serves as identification of the particular parameter which is inserted. The program reads the switches, determines which parameter is being entered, converts it to its binary equivalent, and adjusts it to its proper dimensions of scaling. When this is completed, the system is ready for checkout. System checkout utilizes a simulation tape previously prepared and played back on a magnetic tape recorder. Three channels of the tape recorder are connected as inputs to three hydrophone channels of the ATS. This tape utilizes prerecorded pulses properly spaced in time to simulate target vehicle moving past the array on a pre-determined track. Three tapes are available to simulate a 4-knot rectangular course, a high-speed rectangular course, and an 8-knot elliptical course about the array. Any one of the tapes can be utilized to exercise the system. A complete checkout of the system including the acoustic equipment, system communication, and system phase calibration can be accomplished only in a total system checkout which requires the use of the equipment installed on the target submarine in addition to the equipment carried on MONOB I.

2. ATS (Submarine) Equipment Checkout

During the checkout of the equipment installed on the submarine, the submarine will be requested to drift while on the

surface within a radius of 2000 yd of the AUTEC array. The checkout will include insuring that the 25-kc projector, the communication hydrophone, and the associated electronic equipment are operational. Radio voice communication will be checked out to insure proper coordination with MONOB.

3. System Calibration and Checkout

System calibration and checkout requires the utilization of both the MONOB and submarine ATS equipment. During this phase, the submarine will be requested to operate on the surface at a speed of 5 knots in a rectangular course about the array at a range between 1000 and 2000 yd. The system checkout will consist of the following modes of operation:

a. Phase calibration consists of pinging via the FM transceiver radio link at the selected ping rate. The ping is received aboard MONOB and applied to the ATS System which utilizes the radio ping to calibrate the phase of its real-time clock with that of the submarine. It is necessary to perform or check phase calibration at least once per day. The program always enters the phase test mode upon completion of this mode.

b. Phase calibration test is a separate mode that the program enters into after every phase calibration. Once the phase calibration has been performed, subsequent radio pings are used to check the accuracy of the calibration and indicate either a good or bad calibration by means of a typeout on the typewriter. A test of phase calibration can be performed at any time; however, it will be necessary for the submarine to be on the surface for its performance.

c. The insert mode follows. This is used to enter into the computer those quantities which will vary from one run to another. These quantities include depth of submarine, speed of sound, length of the passive zone, and desired closest point of approach to the array.

C. SYSTEM OPERATION

The system operation is divided into two parts; prerun mode and run mode.

1. Prerun Mode

The prerun mode is that mode of system operation which would customarily be utilized when the submarine is navigating into position to begin a run past the array or throughout any run for which no passive zone is required. During this mode, the submarine is tracked and navigation data are transmitted to aid in guiding it on the desired track.

2. Run Mode

The run mode differs from the prerun mode in that it will contain a passive or noise-measuring zone. During this time, the tracking pinger will be automatically quieted and communication data will cease until the test vessel leaves the passive zone.

Normally, the track which the submarine is requested to follow is along a line perpendicular to the axis of the tracking arm of the array (A.2 Appendix A). The angle between the tracking arm and true north is inserted so that the desired track is always perpendicular to the arm and so that the ATS indicates TRUE submarine bearings.

When the submarine is in position to begin a run past the array, a desired speed, depth and closest point of approach to the array will be transmitted to the test vessel by voice communications or by designation of a run number for which the above parameters have been defined (Fig 11). With the run underway, the test director aboard MONOB will be in a position to follow the course of the test vessel on an X-Y plotter. During the active part of the tracking run, range and true bearing information will be displayed in "Nixie" lights at the remote display console on the submarine. Track deviation to the left or right of the desired course will be indicated in yards on a track error meter also located on the remote display console. The navigation communication is automatically transmitted by the computer via the UQC mounted on the array and received by the ATS communication receiver mounted in the ATS dome on the submarine.*

At the conclusion of each run, any parameter changes can be inserted while the submarine is turning for the next run. Insertion of parameters into the computer requires that communication data be stopped for approximately 1 min.

*MONOB computer informs submarine via communications link when tracking ping is missed. Submarine remote console indicates stale information, holds subject information until next valid ping is received, processed and acted upon. A valid ping is one which falls within a "window" of X & Y parameters which in turn are controlled by the inserted run quantities and program. This feature greatly increases the system immunity to man-made and ambient random pulses thus insuring the presentation of valid information.

TABLE OF RUNS - DIESEL SUBMARINE

Run	Depth	Speed Kts	Propulsion Mode	Remarks	Submarine Use Only: Completed	Submarine Use Only: Remodes
1	Periscope	5	Battery			Bow-Stern
2	Snorkel	5	Diesel	Run all Engines and Charge Batteries		" "
3	"	10	"			Beam
4	200'	5	Battery			
5	"	10	"			
6	"	Max	"	Go to Max Speed at 500 yards		Beam
7	Max	10	"			
8	"	Max	"	Go to Max Speed at 500 yards		Bow-Stern

FIGURE 11 - TYPICAL AGENDA - DIESEL SUBMARINE

V. OPERATING PROCEDURES

At the time this report was written, the AUTEC Acoustic Array was under development; it had been used only during short checkout and calibration tests. Prior to employing this array for actual trials, system characteristics and trial procedures must be developed to protect both the submarine and the rather expensive array. However, an attempt was made (see Trial Results below) to establish certain basic criteria in operational techniques with the array.

Based on these studies, the following procedural recommendations are offered: It is requested that the submarine always pass the array on the deep-water side (eastward) and always attempt to turn away from the array in the event of a terminated run or an emergency.

It is suggested that several orientation runs at periscope depth and at various speeds be made past the array in order to compare DRT plots, sonar information, and actual surface navigation with the proposed tracks. A systems (ranging) checkout should be undertaken during these runs in order to determine the effects of the existing water currents on the position of the array and on the orientation of the tracking arm.

The Model Basin Trial Director will normally announce the type of run as well as the run number for performance of acoustic runs. Generally the two basic types are bow-stern and beam. The information indicated below has been successfully used in trial conduct but it is envisioned these CPA parameters for bow stern runs will change. This will be reflected in the appropriate agenda.

(1) In performing bow-stern runs, the submarine will close range from 1000 yd, pass the hydrophone array at 50 yd, and open range to 1000 yd. Radio or voice UQC transmissions should be held to a minimum between 500 yd approaching and 500 yd opening. Throughout this interval, the course is to be followed as accurately as possible and rudder angles are to be kept as small as practicable.

(2) In performing the beam aspect runs, the submarine will start the acoustic portion of the runs at $\pm$ 40 deg from the center bearing (090 or 270 deg) and pass the array with a CPA range of 200-300 yd. Radio or voice UQC transmissions should be held to a minimum. For both these type runs, constant speed, course and machinery conditions are required. Noise recordings will be made commencing at 1000-yd range closing and through CPA to 1000-yd opening.

Straight-course runs of the bow-stern (50 yd CPA) and 200 yd beam aspect type have provided submarine noise measurements that are considered especially valuable. Normally data are analyzed at a range of 125 to 400 yd from CPA, depending on sea state and the machinery bill. The detectability of many acoustic sources changes with aspect angle, and for this reason it is necessary to have a means of obtaining bow, stern, and beam aspect data separately.

For identifying certain very troublesome noise sources, runs at various speeds and depths are practically indispensible and are to be conducted in conjunction with the AUTEC array. The prescribed course is circular, and the range to the array should be less than 500 yd*. Range control for this run is not important, provided the submarine remains within a 500-yd radius. Source strength is not measured for these runs.

*Obviously, during circular runs, there is no objection to the submarine passing inshore of the array. There is an adequate extent of deep water for this purpose.

Hovering runs are still required to supplement overside data obtained from builders trials. Present plans are to measure the noise from auxiliary machinery with the submarine drifting 150-250 yd from the point, maintaining a position immediately above the array by intermittent use of the main engines at very low rpm. Measurements are discontinued while the position of the submarine is being corrected.

VI. LIMITED TRIAL RESULTS

A recent on-site checkout test with a Guppy fleet vessel resulted in establishing certain operational features heretofore not available.

Surface runs normally initiated each day's operation, including FM phase calibration checks of the ATS.

During checkout, flooding out of one of the tracking hydrophones made it necessary to use a spare hydrophone, which reduced the tracking hydrophone baseline from the normal 40 ft to 20 ft. Under this condition the following was noted:

1. Range errors did not exceed 25 yd and improved as the range to the array was closed. A preliminary study of the actual system error based on recorded trial data has been conducted. Examination of the theoretical error analysis (as per IBM) indicates that the R_H calculation is more accurate than the y calculation. This is principally due to R_H being only a function of depth and total travel time measurement, two of the minor error contributors. At the point of closest approach (x=o) R_H and y should be equal. Any result other than zero for $[R_H - y]_{x=0}$ could be interpreted as predominantly error in the y calculation. Values

of $[R_N - y]$ have been tabulated since the sea tests and comparison against theoretical errors in y have been made. An average error in y was determined to be 75 feet. This result compares favorably with the theory which indicates that theoretical assumptions selected for the analysis appear to be reasonable. A tentative conclusion may be drawn. Actual errors in x become excessive near the axis and consequently difficulties in crossing the axis do exist. The importance of the larger baseline is again stressed. Much of the problem in crossing the y axis witnessed on the test would have been minimized if the 46 foot baseline was usable. Investigations in this area are continuing to reduce the average error noted.

2. Bearing error for typical CPA ranges was minimum at long ranges, i.e., 1.5 deg at 1000 yd, approximately 1 deg at $\pm$1500 yd. This provides maximum assistance during positioning for test run.

3. Bearing error increased as range to the array closed and exceeded 3 deg at ranges less than 300 yd. This is not considered serious because the test vehicle is well committed by this time and should be able to maintain proper course and pass the array properly and safely.

The restoration of the 40-ft baseline will decrease the bearing error markedly. Although it will not decrease the range error, it is considered necessary to improve the margin of safety. Additional spare tracking hydrophones, arranged to provide maximum protection for the full 40 ft tracking baseline and embodying improved water-tight integrity, will be installed on the array.

Array active beacons and sonar reflectors proved effective for guidance purposes out to 12,000 yd, and it is suggested that these beacons and submarine active sonar at long ranges be utilized when repositioning for a new run. The ATS can then be resorted to, and reliance given when the test vehicle comes into its operating range (4000-5000 yd).

Bearing changes of the tracking arm are shown (Figure 12). These variations were available in true bearing through the use of a flux gate compass mounted on one end of the tracking arm, with readout available in the laboratory vessel. As bearings were read periodically throughout each test day in 1962 and 1963, the ordinate in Figure 12 (number of observations at each bearing) is proportional to the relative amount of time the tracking arm is likely to spend at that bearing. It was observed that the orientation of the tracking arm was related to tidal changes in the area. This can be considered a result of ocean semidiurnal and mixed tides and/or currents. Experiments have been conducted which suggest the vertical hydrophone array has little or no tilt from the vertical due to currents.

Studies are being undertaken to make the ATS independent of radio link for phase calibration. Certain difficulties inherent in the antenna system occasionally result in unsatisfactory communications via FM for phase calibration.

It has been recommended by the Commanding Officer of a recent test vehicle that a "cutoff point" when closing the array be established.

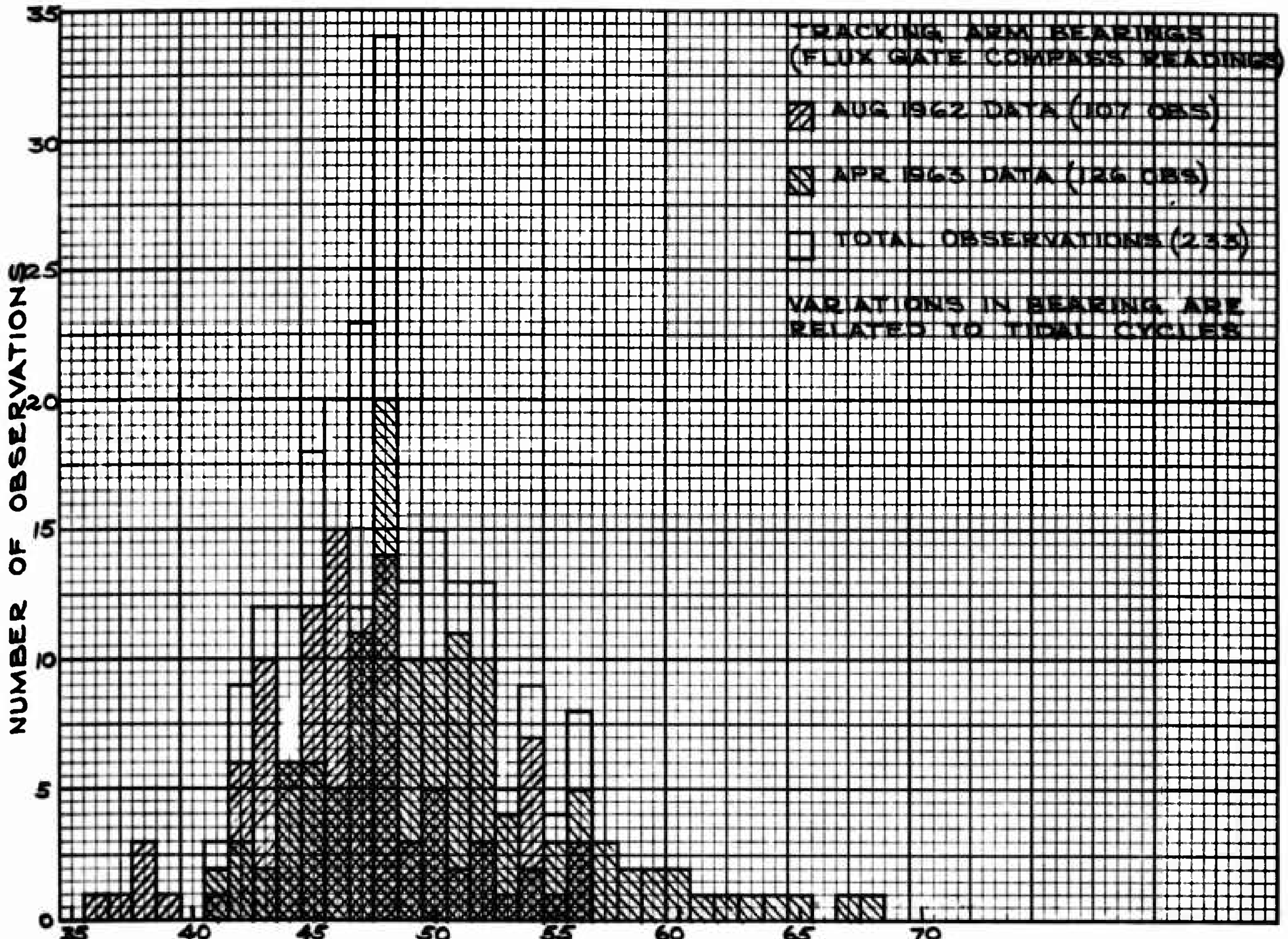


Figure 12 - Array Tracking Arm Bearing (Degree True)

If while closing the array within the quiet zone, the ATS computed track error was towards the array and exceeded the cutoff value, then "turn away" would follow with a resultant abortion of the run. This cutoff value so established would be a function of speed, depth, and CPA distance. No course changes would normally occur in this quiet zone except in emergencies.

Constant monitoring and plotting both on the test vehicle and MONOB I are indicated in order to recommend or make necessary course changes, including turn away if it becomes necessary.

On the whole, ATS behaved very well during these tests. The difficulties encountered were no more severe than would normally be expected at this stage of the development process. The tracking accuracy found in these trials is adequate for acoustic tests.

ACKNOWLEDGMENTS

The authors are grateful to Mr. George Boyer of the International Business Machine Corporation for his assistance in furnishing information and photographs to be incorporated into the body of this report. Sincere thanks are due the Commanding Officers and crews of USS BUSHNELL (AS-15), USS THREADFIN (SS-410), and USS CHOPPER (SS-342) for their spirit and cooperation during the installation and checkout phases of the evaluation of the ATS. Appreciation is also extended to Messrs. Curtis, Gilbert, and Gaynor for their assistance in the original planning and development of the system. Messrs. Cole and Boswell of Code 088 gave invaluable assistance in the preparation of this report.

APPENDIX A

AUTEC MATHEMATICS

1. Figure A.1 Geometry
2. Figure A.2 Straight Track
3. Figure A.3 Straight Skewed Track*
4. Figure A.4 Circular Track*
5. Figure A.5 Figure Eight Track*
6. List of Variables
7. List of Constants
8. List of Insert Quantities
9. Inputs to Acoustic Tracking System
10. Formulae

*A non standard type of track requiring modified mathematics.

Appendix A

AUTEC GEOMETRY

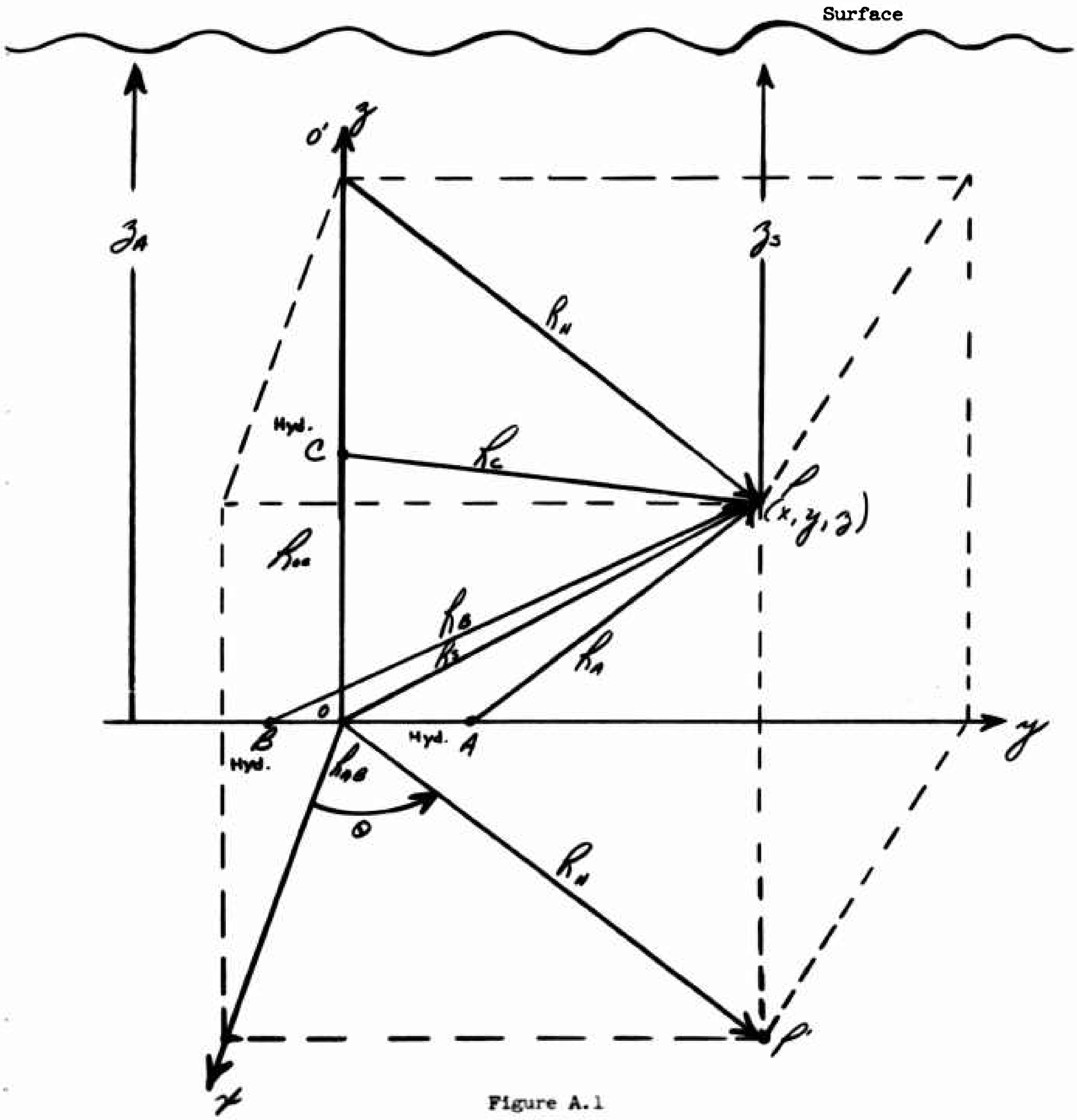


Figure A.1

STRAIGHT TRACK

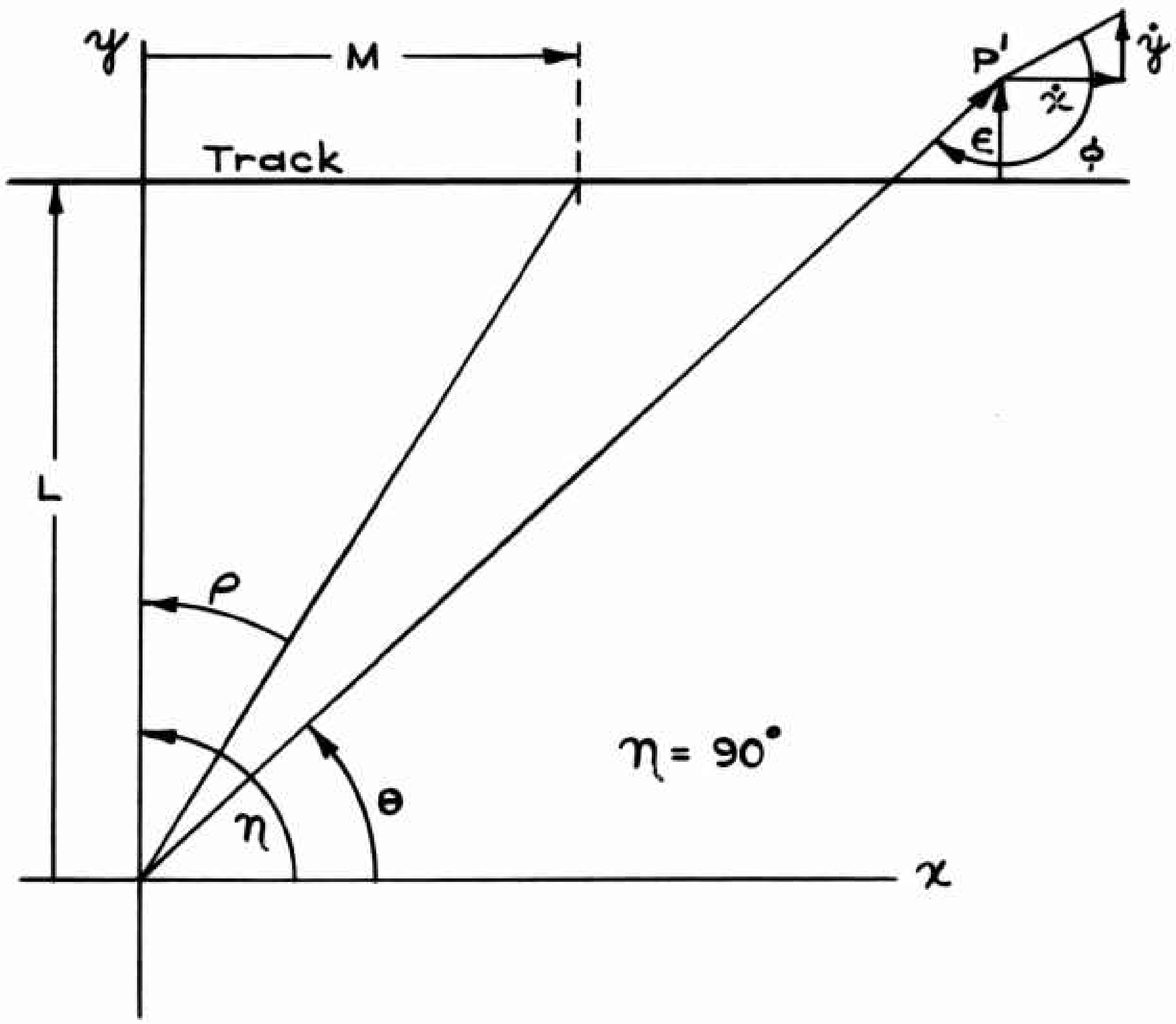


FIGURE A.2

Appendix A

STRAIGHT SKEWED TRACK

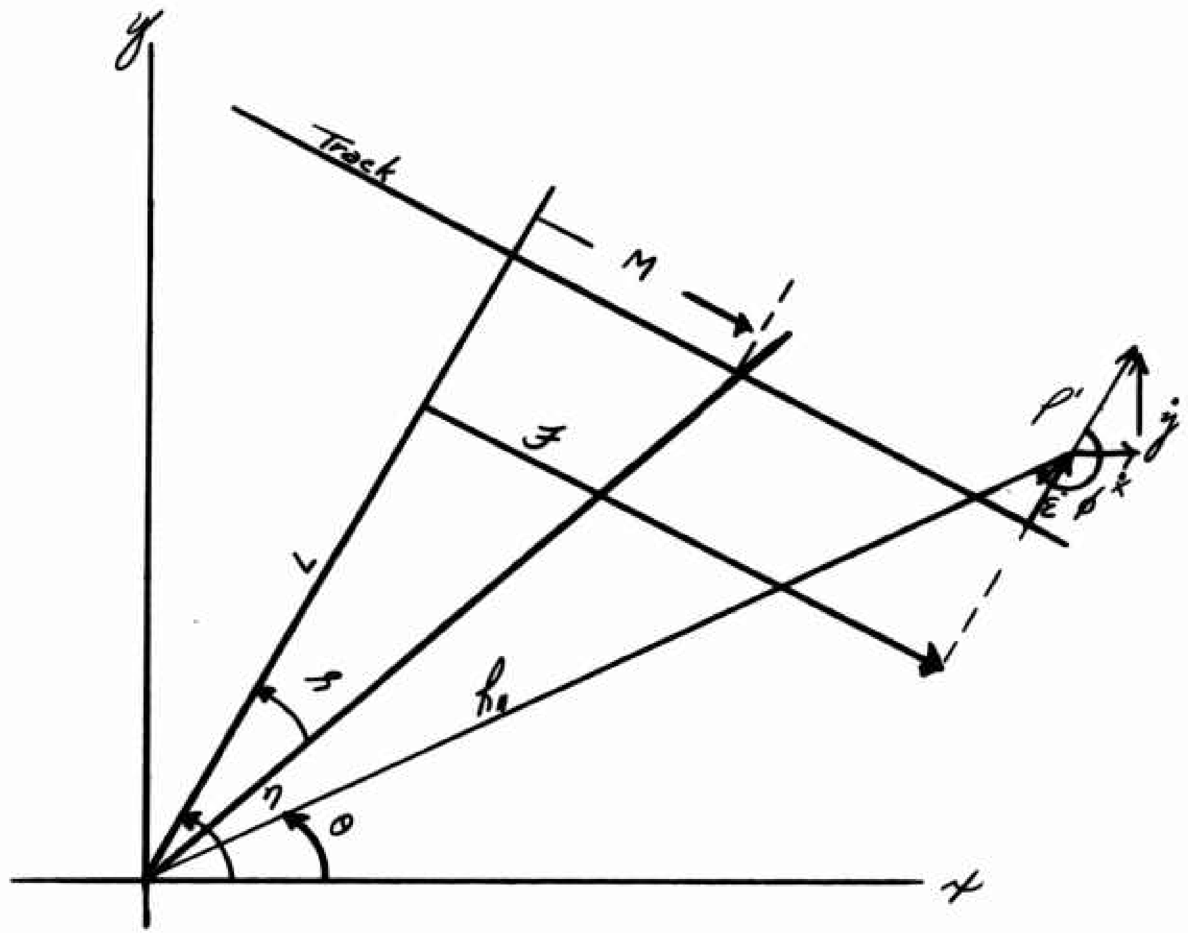


Figure A.3

Appendix A

CIRCULAR TRACK

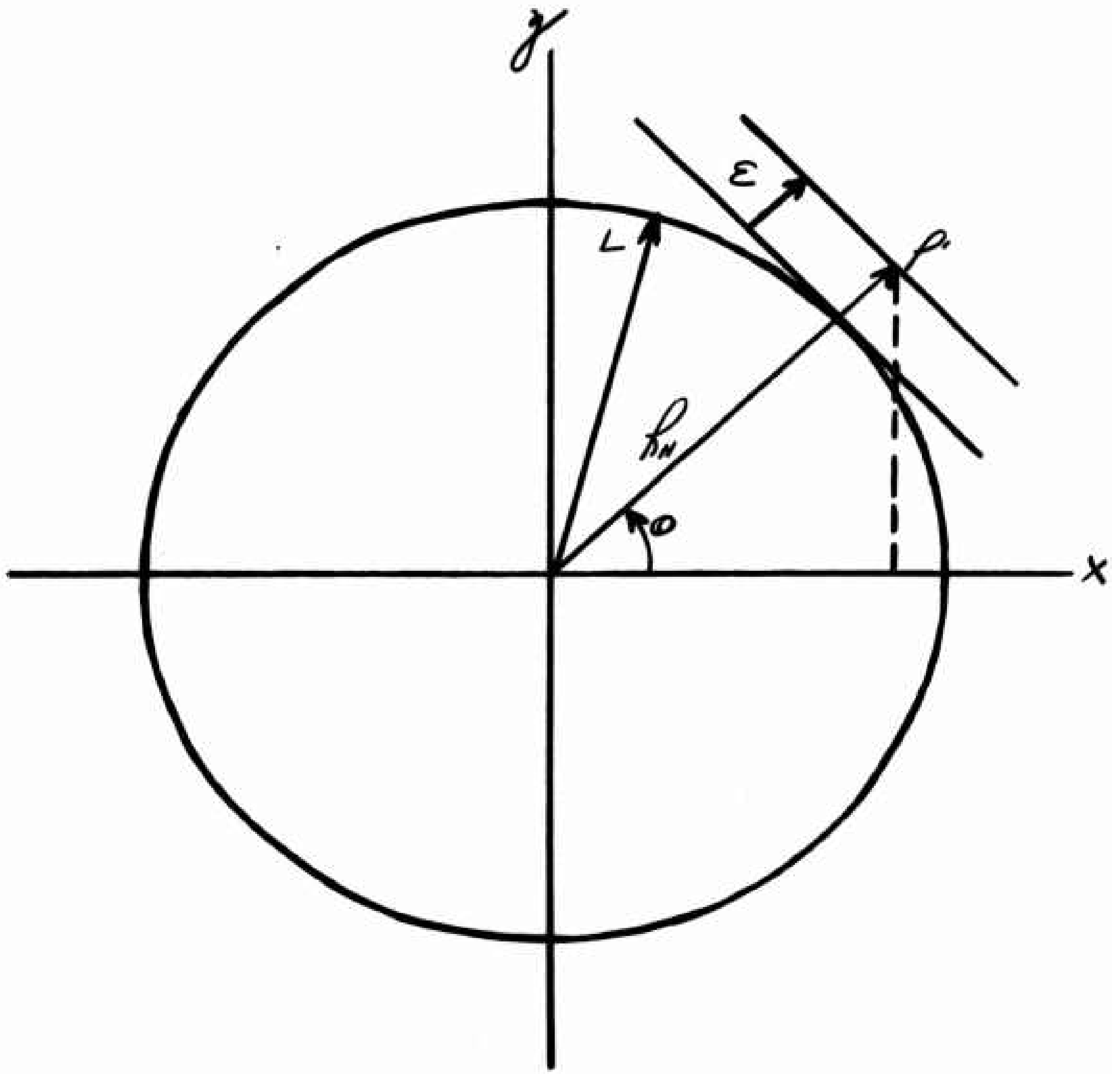


Figure A.4

FIGURE EIGHT TRACK

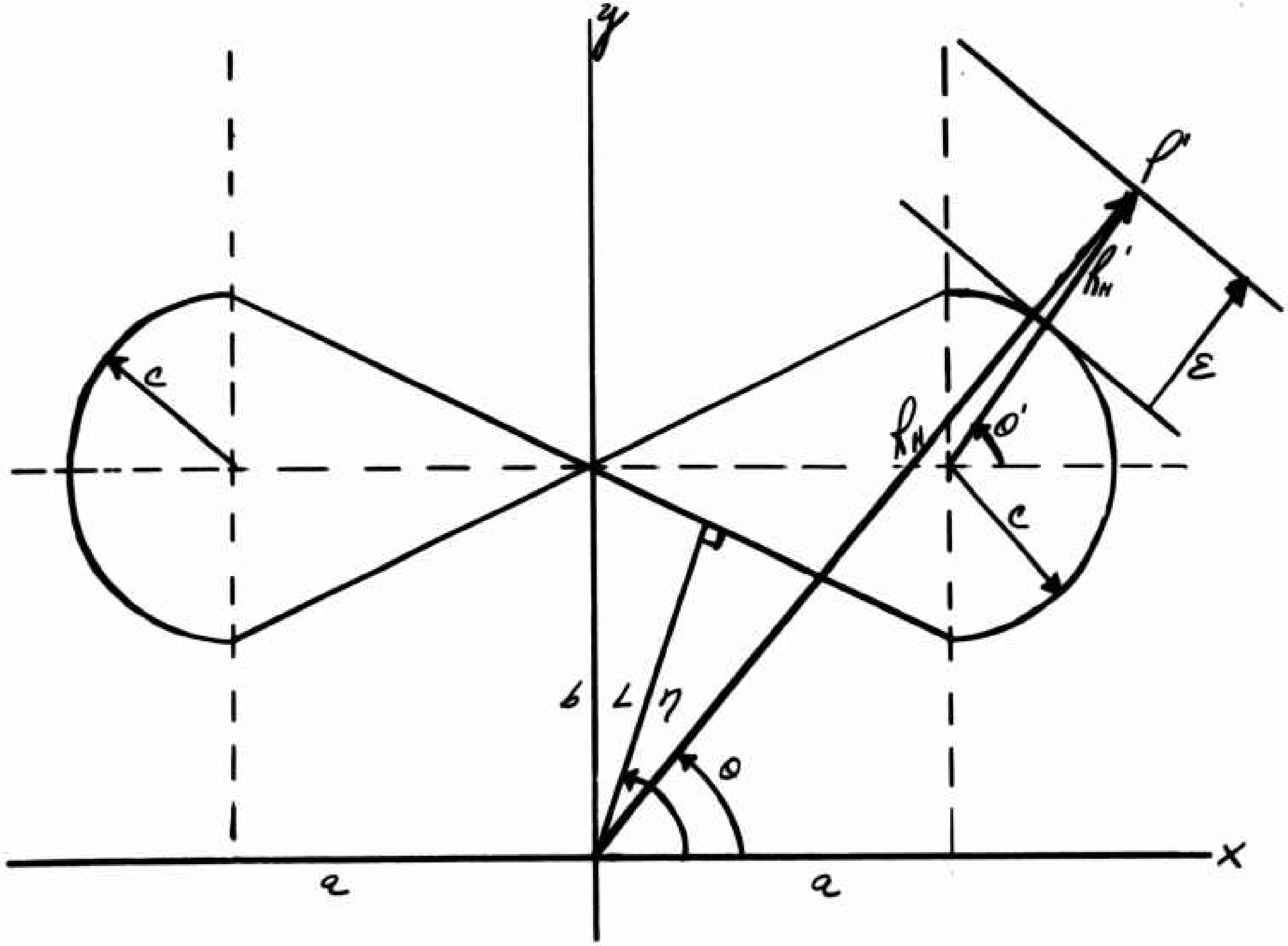


Figure A.5

Appendix A

LIST OF VARIABLES

No.	Symbol	Name
1	T_A	Travel Time Sub to Hydrophone A
2	T_B	Travel Time Sub to Hydrophone B
3	T_C	Travel Time Sub to Hydrophone C
4	R_A	Range Sub to Hydrophone A
5	R_B	Range Sub to Hydrophone B
6	R_C	Range Sub to Hydrophone C
7	R_S	Slant Range
8	R_H	Horizontal Range
9	θ	Sub Bearing Angle
10	x	Sub x Coordinate
11	y	Sub y Coordinate
12	z	Sub z Coordinate
13	z_A	Array Depth Below Surface
14	z_S	Sub Depth Below Surface
15	K_x	Sign of x
16	$\dot{x}$	Time Rate of Change of x
17	$\dot{y}$	Time Rate of Change of y
18	ϕ	Array Bearing Angle From Sub Velocity Vector
19	ε	Lateral Deviation
20	$\dot{\varepsilon}$	Time Rate of Change of Lateral Deviation
21	v	Guidance Signal
22	K_{sj}	Sign of v, $j = s$ or c
23	$\mathcal{F}$	Range of Sub Along Track

Appendix A

LIST OF VARIABLES (Continued)

No.	Symbol	Name
24	$\dot{x}$	Time Rate of Change of Sub Along Track
25	N_1	Integer Count to Passive Zone
26	N_1'	Exact Count to Passive Zone
27	N_2	Integer Count to Ping of Closest Approach
28	N_2'	Exact Count to Ping of Closest Approach
29	N_{1R}	Remainder of N_1
30	$\dot{R}_H$	Rate of Change of Horizontal Range
31	$\dot{\theta}$	Rate of Change of Array Bearing Angle
32	R_1	Slant Range to Hydrophone 1
33	R_2	Slant Range to Hydrophone 2
34	R_3	Slant Range to Hydrophone 3
35	R_4	Slant Range to Hydrophone 4
36	R_5	Slant Range to Hydrophone 5
37	T_1	Travel Time to Hydrophone 1
38	T_2	Travel Time to Hydrophone 2
39	T_3	Travel Time to Hydrophone 3
40	T_4	Travel Time to Hydrophone 4
41	T_5	Travel Time to Hydrophone 5
42	R_H'	Horizontal Range From Coordinates (a,b)
43	$\dot{R}_H'$	Rate of Change of Horizontal Range From Coordinates (a,b)
44	a	X Coordinate of Figure Eight Circle Origin
45	b	Y Coordinate of Figure Eight Circle Origin

Appendix A

LIST OF VARIABLES (Continued)

No.	Symbol	Name
46	e	Radius of Figure Eight Circle
47	θ'	Sub Bearing From Coordinates (a, b)
48	$\dot{\theta}'$	Rate of Change of Sub Bearing From Coordinates (a, b)

Appendix A

LIST OF CONSTANTS

No.	Symbol	Name
1	C	Speed of Sound
2	δ	Smoothing Constant
3	$_nP$	Ping Period, n = 1, 2 and 4
4	η	Track Angle
5	L	Track Distance
6	J	Passive Zone Angle
7	M	Passive Zone Distance
8	K_a	Proportional Constant
9	K_σ	Rate Constant
10	R_{AB}	Distance Between Hydrophone A and Hydrophone B
11	R_{OC}	Distance Between Hydrophone C and Origin

Appendix A

LIST OF INSERT QUANTITIES

No.	Symbol	Name
Inputs		
1	c	Speed of Sound
2	η	Track Angle
3	L	Track Distance
4	$\mathcal{J}$	Passive Zone Angle
5	z_s	Depth of Sub Below Surface
6	a	X Coordinate of Figure Eight Circle Origin
7	$_nP$	Ping Period, = 1, 2 and 4
8	k_x	Sign of X
9	Spare	
10	Spare	
11	Spare	
12	Spare	

Appendix A

INPUTS TO ACOUSTIC TRACKING SYSTEM

No.	Symbol	Name
1	T_A	Travel Time Hydrophone A
2	T_B	Travel Time Hydrophone B
3	T_C	Travel Time Hydrophone C
4	T_1	Travel Time Hydrophone 1 *
5	T_2	Travel Time Hydrophone 2 *
6	T_3	Travel Time Hydrophone 3 *
7	T_4	Travel Time Hydrophone 4 *
8	T_5	Travel Time Hydrophone 5 *

*Total of five noise hydrophones in any order may be selected from total number of noise hydrophones available on array in use.

Appendix A

D/A OUTPUTS

No.	Symbol	Equipment Name
1	X	Plotter
2	Y	Plotter
3	R_s	Tape
4	θ	Tape
5	R_H	Comm.
6	ϕ	Comm.
7	σ	Comm.
8	N_1	Comm.
9	N_2	Comm.
10	R_1	Tape
11	R_2	Tape
12	R_3	Tape
13	R_4	Tape
14	R_5	Tape

Appendix A

TYPEOUT

No.	Symbol	Name
1	c	Speed of Sound
2	η	Track Angle
3	L	Track Distance
4	σ	Passive Zone Angle
5	z_A	Depth of Array Below Surface
6	z_S	Depth of Sub Below Surface
7	R_S	Slant Range
8	R_1	Range to Hydrophone 1
9	R_2	Range to Hydrophone 2
10	R_3	Range to Hydrophone 3
11	R_4	Range to Hydrophone 4
12	R_5	Range to Hydrophone 5
13	θ	Sub Bearing Angle
14	a	X Coordinate of Figure Eight Circle Origin

Note:

a. 1-6 on Insert

b. 7-12 on Request

Appendix A

FORMULAE

1. Range

$R_j = cT_j$ $\qquad j$ = A, B, C, 1, 2, 3, 4 and 5

2. Slant Range

$$R_s^2 = \frac{R_A^2 + R_B^2}{2} - \left(\frac{R_{AB}}{2}\right)^2$$

3. Depth

Case a - Insert

$z = z_A - z_S$

Case b - Calculate

$$z = \frac{R_S^2 - R_C^2}{2R_{OC}} + \frac{R_{OC}}{2}$$

$z = z_A - z$

4. Horizontal Range

$z = z_A - z_S$

$R_H^2 = R_S^2 - z^2$

5. Cartesian Coordinates and Bearing

$$y = \frac{R_B^2 - R_A^2}{2R_{AB}}$$

$\theta = \sin^{-1} y/R_H$

$x = K_x\sqrt{R_H^2 - y^2}$

6. Array Bearing

$$|\sin\phi| = \frac{|x\dot{y} - \dot{x}y|}{R_H\sqrt{\dot{x}^2 + \dot{y}^2}}$$

7. Navigation

a. Straight Skewed or Perpendicular

$\mathcal{E}_S = x\cos\eta + y\sin\eta - L$

$\dot{\mathcal{E}}_S = \dot{x}\cos\eta + \dot{y}\sin\eta$

$\mathcal{F} = x\sin\eta - y\cos\eta$

$\dot{\mathcal{F}} = \dot{x}\sin\eta - \dot{y}\cos\eta$

$V_S = k_{SS}(K_d\mathcal{E}_S + K_v\dot{\mathcal{E}}_S)$

Appendix A

FORMULAE (Continued)

b. Circular Track

$$\mathcal{E}_c = R_N - L$$

$$\dot{\mathcal{E}}_c = \frac{x\dot{x} + y\dot{y}}{R_N}$$

$$\dot{\theta} = \frac{x\dot{y} - \dot{x}y}{R_N^2}$$

$$V_c = K_{sc}\left(K_M \mathcal{E}_c + K_V \dot{\mathcal{E}}_c\right)$$

c. Figure Eight Track

(1) Case 1: $|x| \leq a$

$$\mathcal{E}_{L_1} = x \cos\eta + y \sin\eta - L$$

$$\dot{\mathcal{E}}_{L_1} = \dot{x} \cos\eta + \dot{y} \sin\eta$$

$$V_{L_1} = K_{sL_1}\left(K_M \mathcal{E}_{L_1} + K_V \dot{\mathcal{E}}_{L_1}\right)$$

(2) Case 2: $|x| > a$

$$b = L/\sin\eta$$

$$c = a/\tan\eta$$

$$R_N'^2 = (x-a)^2 + (y-b)^2$$

$$\dot{R}_N' = \frac{(x-a)\dot{x} + (y-b)\dot{y}}{R_N'}$$

$$\mathcal{E}_{L_2} = R_N' - c$$

$$\dot{\mathcal{E}}_{L_2} = \dot{R}_N'$$

$$V_{L_2} = K_{sL_2}\left(K_M \mathcal{E}_{L_2} + K_V \dot{\mathcal{E}}_{L_2}\right)$$

8. Active-Passive Zone Control

Case 1 - Straight and Figure Eight Tracks

$$N_1' = \frac{\mathcal{J} - M}{\mathcal{J}_{np}} \qquad M = L \sin \mathcal{J}$$

$$N_1 = \left(N_1' + \tfrac{1}{2}\right) \qquad N_2' = \frac{M}{\mathcal{J}_{np}} + N_{1R}$$

$$N_{1R} = N_1' - N_1 \qquad N_2 = \left(N_2' + \tfrac{1}{2}\right)$$

Case 2 - Circular Track

$$N_1 = N_1(MAX)$$

$$N_2 = 0$$

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